List of Potential Control Measures for PM2.5 and Precursors:

Introduction and Caveats

These informational documents provide a broad, though not comprehensive, listing of potential emission reduction measures for direct PM2.5 and precursors. The purpose is primarily to assist states in identifying and evaluating potential measures as states develop plans for meeting the PM2.5 NAAQS as expeditiously as practicable.

The severity, nature and sources of the PM2.5 problem vary for different nonattainment areas, so the measures that are effective and cost-effective will vary for different areas. Similarly, the geographic area in which measures are applied may vary depending on factors such as the extent to which pollution sources outside the nonattainment area contribute to the area's PM2.5 problem.

This PM2.5 control measures list includes the following components:

- **1. Stationary/area source measures list:** Separate tables of measures are available for three pollutants:
  - PM2.5
  - SO2
  - NOx

  For most measures, the table provides an estimate of the control efficiency and, the cost per ton of pollutant reduced. The tables also identify reference sources that the user may wish to consult for more information. In addition, for direct PM2.5, the table suggests a number of possible plant-specific engineering evaluations for which no generalized cost estimate is given.

- **2. On-road mobile source measures lists:** Separate tables of measures are provided for three pollutants.
  - PM2.5
  - SO2
  - NOx

  Reference sources are provided as available.

- **3. Non-road mobile source measures lists:** Separate tables of measures are provided for three pollutants.
  - PM2.5
  - SO2
  - NOx

  Reference sources are provided as well as a detailed list of control measures.

- **4. Supplemental appendix on ammonia and on-road VOC measures**: In the notice of proposed rulemaking for the PM2.5 implementation, EPA proposed to make a legal presumption that VOCs and ammonia would not be regulated precursors for purposes of a nonattainment area's PM2.5 plan, unless the state or EPA makes a determination to the contrary. In light of this, information on certain selected measures that reduce emissions of ammonia and/or VOC is provided in a separate, supplemental appendix. Tables are available for:

- On-road VOC measures: measures that are listed in the on-road measures table for PM, SO2 and/or NOx, and that also reduce VOC. (The mobile VOC measure information may also be useful in the ozone SIP context.)
- On-road ammonia measures: measures that are listed in the on-road measures table for PM, SO2 and/or NOx, and that also reduce ammonia.
- Stationary/area source ammonia measures: these measures were applied in EPA's PM NAAQS Regulatory Impact Analysis. Please note that this is not intended as a broad listing of potential VOC or ammonia measures.

Reference sources are also provided for both onroad VOCs and ammonia.

Energy efficiency and renewable energy measures list: A fifth list, currently under development, will include energy efficiency and renewable energy measures that can help reduce emissions of PM2.5 and precursors in the short run and in the longer run.

"Living documents": These documents are a joint effort of EPA's Office of Air Quality Planning and Standards, Office of Transportation and Air Quality, Office of Atmospheric Programs, and Office of Policy Analysis and Review. Contractor assistance was provided by ICF Consulting and subcontractor E.H. Pechan. We regard these as "living documents" and have labeled them as "Draft" to reflect that as we use these documents, we expect to make ongoing revisions as we receive additional information from states and others. We invite users to provide suggestions if they know of additional measures, or additional information sources on measures, that they believe should be included. We are interested in adding any such additional measures especially for sources that are making contributions to PM2.5 nonattainment. (Contact points: Tim Smith, OAQPS, 919-541-4718, Smith.Tim@epa.gov, (stationary/area); Rudolph Kapichak, OTAQ, 734-214-4574 Kapichak.Rudolph@epa.gov (mobile); Sam Waltzer, 202-343-9175, Waltzer.sam@epa.gov (EGU).)

As mentioned above, this list is broad but not comprehensive. We have striven to make the list relevant to states by omitting mention of some measures that our staff understands may already be employed by virtually all sources, or by providing summary mention of certain measures that may be relevant to source categories. For example, for direct PM2.5 sources, a table of PM2.5 controls could have identified, in encyclopedic fashion, the source categories for PM2.5 sources and the add-on controls which are applied to sources in those categories -- such as baghouses, electrostatic precipitators and venturi scrubbers. Our general view was that this would be largely "reinventing the wheel" on controls in place rather than shedding useful insights on means for additional emission reductions.

Measures listed more than once: Note that some emission reduction measures (e.g., many of the mobile source measures) are listed in more than one table of measures, because they reduce multiple pollutants. For example, a measure that reduces both direct PM and NOx appears once in the PM measures table, and once in the NOx measures table.

Potential Stationary and Area Source Measures for PM2.5

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Generally applicable measures							
All industrial and commercial sources emitting direct PM2.5	Review uncontrolled or under controlled stack sources for improvements						**EPA 2002, EPA 1998b,** AWMA 2000,STAPPA/ALAPCO 2006, Pechan and RTI 2005a, Pechan and RTI 2005b.
All industrial and commercial sources currently controlling PM with cyclones or multicylones	Upgrade to high-efficiency collection device to collect fine fraction of PM						**EPA 1998b,** AWMA 2000, EPA 2002
All industrial and commercial sources currently controlled by electrostatic precipitators (ESPs)	Upgrade ESP to improve efficiency on fine fraction of PM, for example by increasing size/SCA, flue gas conditioning, or use of hybrid technologies to improve performance						**Pechan and RTI 2005b**
All industrial and commercial sources currently controlled by fabric filters	Improved monitoring to reduce baghouse malfunctions (e.g., bag leak detectors)						**Pechan and RTI, 2005b,** EPA 1997b.
Industrial process fugitives and open dust fugitive emissions sources	Improve fugitive emissions capture						**WRAP 2004**, STAPPA/ALAPCO 2006
All industrial and commercial sources with PM control devices including baghouses, ESPs, and venturi scrubbers	Increased Monitoring Frequency of PM Controls	6.5	$620	2003$			**Barr and Schaffner, 2003, EPA 2000a**
All industrial and commercial sources with PM control devices including baghouses, ESPs, and venturi scrubbers	Increased Monitoring Frequency of PM Controls + PM CEMS	7.7	$5,200	2003$			**Barr and Schaffner, 2003, EPA 2000a**
All sources of condensable PM2.5	Evaluate whether can feasibly reduce temperature of gas stream and increase collection of condensables, and whether can collect with wet ESPs or other devices						[We are looking for references on this topic]
Category specific point source measures							
Cement Manufacturing	Process equipment vented to baghouse. Various controls for open storage piles, primary crushing operations, and conveying systems.				Process equipment limits: 0.01 gr/dscf for existing equipment; 0.005 gr/dscf for new equipment		SCAQMD, 2005a

Potential Stationary and Area Source Measures for PM2.5

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Ferrous Metals Processing - Iron and Steel Production - Blast Furnace Casthouse	Capture Hood Vented to a Baghouse	85			Uncertainty relatively high. Based on engineering judgments and MACT data which for some plants may be outdated.		**EPA 2006a**, Pechan 2006
Ferrous Metals Processing - Iron and Steel Production - BOF	Secondary Capture and Control System	85	$5,000		Uncertainty relatively high. Based on engineering judgments and MACT data which for some plants may be outdated.		**EPA 2006a**, Pechan 2006
Ferrous Metals Processing - Iron and Steel Production - Sinter Plant	Install baghouse to control emissions from sinter cooler	99	$5,000	2001$	Uncertainty relatively high. Based on engineering judgments and MACT data which for some plants may be outdated.		**EPA 2006a**, Pechan 2006
Petroleum Refinery Catalytic and Thermal Cracking Units	Wet Scrubbing	85 - 95	Not Available				**MARAMA, 2006**
Petroleum Refinery Catalytic and Thermal Cracking Units	Electrostatic Precipitators	>95%	$ 3500 - 6600				**MARAMA, 2006;** SCAQMD, 2003
Petroleum Refinery Catalytic and Thermal Cracking Units	Sodium bisulfite (SBS) injection	Not given	Not given				**MARAMA, 2006**
Stationary diesel engines including generators and other prime service engines	Diesel oxidation catalyst (where DPF not feasible)	20	$1,000-$2,000	2003$	Cost effectiveness is based on the combined CO, HC, NOx and PM reduction		**NESCAUM 2003**, STAPPA and ALAPCO 2006
Stationary diesel engines including generators and other prime service engines	Diesel particulate filter	80-90	$2,000-$19,000	2003$	Cost effectiveness is based on the combined CO, HC and PM reduction; 'Development measure from PM NAAQS RIA		**NESCAUM 2003**, STAPPA and ALAPCO 2006.
Coal-fired Utility Boiler currently controlled by ESPs	Indigo Agglomerator	40	Cost effectiveness is variable and based on plant size: the total capital cost of $8 per kW	2005$			**Khan, EPA. August 21, 2006.**

Potential Stationary and Area Source Measures for PM2.5

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Coal-fired Utility Boiler currently controlled by ESPs	Add enough collection area to equal one field	44	Cost effectiveness is variable and based on plant size: the total capital cost of $13.75 per kW	2005$			**Khan, EPA, August 21, 2006**
Coal-fired Utility Boiler currently controlled by ESPs	Add enough collection area to equal two fields	67	Cost effectiveness is variable and based on plant size: the total capital cost of $17.50 per kW	2005$	CE is incremental to ESP controls		**Khan, EPA, August 21, 2006**
Residual Oil-Fired Utility and Industrial Boilers currently without add-on controls	ESP						**EPA, 2006b.**
Ferroalloy production	Improve capture on open furnaces						**EPA, 2006b.**
Ferroalloy production	Capture of fugitive emissions from pouring and casting						**EPA, 2006b.**
Refractory products manufacturing - non-clay with organic binders	thermal oxidizer on plants below MACT applicability cutoff						**EPA, 2006b.**
Refractory products manufacturing - non-clay with chromium	Fabric filter						**EPA, 2006b.**
Refractory products manufacturing - clay	Wet or dry lime scrubber for plants below MACT applicability limit						**EPA, 2006b.**
Category-specific area source measures							
Commercial Cooking -- conveyorized charbroiler	Catalytic Oxidizer	83	$3,000	2001$		90 % co-control of VOCs	**Ventura County 2004,** CE-ERT 2002
Commercial Cooking -- large underfired grilling operations	Small ESP (e.g., SMOG-HOG) or scrubber	99	$6,000	2003$			**Sorrels 2006**
Agricultural Burning	Alternative to open field burning (e.g., bale or stack burning and propane flamers)	25	$2,591 per ton PM10	1992$	Cost varies by state and plant type, the number here is the cost for Alabama		Pechan 2006
Open Burning of Land Clearing Debris	Substitution of landfilling for open burning	50 to 100	$3,500	1999$	Development measure from PM NAAQS RIA		EPA 2006
Residential Wood Combustion	Education and Advisory Program	5-10	$1,320 per ton PM10	1990$			Pechan 1997
Residential Wood Stoves	Woodstove Changeout Program, including financial incentives and information/encouragement when houses are sold	variable depending on outreach and incentives	$2,000	1999$	'Development measure from PM NAAQS RIA		EPA Communication

Potential Stationary and Area Source Measures for PM2.5

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Residential Wood Stoves	Mandatory changeout when houses are sold	5-7% per year			5-7% is based on typical rates of housing turnover		
Residential Fireplaces	Promote use of Gas Logs/ elimination of wood burning						
Outdoor wood hydronic heaters	Emissions standards or setback requirements						**NESCAUM 2006**
Fugitive Dust Measures							
Abrasive blasting	Water spray	50-93% (PM10)					**WRAP 2006**
Abrasive blasting	Enclosure, fabric filter	95% (PM10)					**WRAP 2006**
Agricultural Lands	Control measures to reduce wind erosion (barriers, cover crop, cross-wind ridges, mulching, planting trees)	25 to 93					**WRAP 2006**
Agricultural Tilling	Soil Conservation Plans	35 to 60	$138 per ton PM10 reduced	1990$			**Pechan 1997,** WRAP 2006
Agricultural Harvesting	Various measures indicated in WRAP manual	5- 70% (PM10)					**WRAP 2006**
Beef Cattle Feedlots	Watering	25	$307	1990$			**Pechan 2006**
Livestock husbandry	Daily watering of corrals and pens, Add wood chips or mulch to working areas	> 10% for PM10					**WRAP 2006**
Construction/demolition	Control measures identified in WRAP fugitive dust manual, Chapter 3						**WRAP 2006**
Mineral products industry wide variety of sources	Control measures identified in WRAP fugitive dust manual, chapter 11						**WRAP 2006**
Agricultural wind erosion	Control measures identified in WRAP fugitive dust manual, chapter 7						**WRAP 2006**
Open area wind erosion	Control measures identified in WRAP fugitive dust manual, chapter 8						**WRAP 2006**
Storage pile wind erosion	Control measures identified in WRAP fugitive dust manual, chapter 9						**WRAP 2006**

Potential Stationary and Area Source Measures for SO2

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Cement Kilns - Wet Process	Wet Gas Scrubber	90	$6,000-$8,000	2002$			**NESCAM 2002**
Cement Kilns - Long Dry Process	Wet Gas Scrubber	90	$3,000-$5,000	2002$			**NESCAM 2002**
Cement Kilns - Long Dry Process	Spray Dryer Absorber	90	$3,000-$5,000	2002$			**NESCAM 2002**
Cement Kilns - Preheater Process Kiln	Wet Gas Scrubber	90	$20,000-$50,000	2002$			**NESCAM 2002**
Cement Kilns - Preheater Process Kiln	Spray Dryer Absorber	90	$20,000-$50,000	2002$			**NESCAM 2002**
Cement Kilns - Preheater/Precalciner Kiln	Wet Gas Scrubber	90	$20,000-$30,000	2002$			**NESCAM 2002**
Cement Kilns - Preheater/Precalciner Kiln	Spray Dryer Absorber	90	$20,000-$30,000	2002$			**NESCAM 2002**
ICI Boilers-Coal--High Sulfur	In duct sorbent injection	40	$633-$1,292	2003$			**EPA 2003a**
ICI Boilers-Coal--High Sulfur	Flue Gas Desulfurization	90	$373-$1,046	2003$			**EPA 2003a**
ICI Boilers-Coal--Low Sulfur	In duct Sorbent Injection	40	$697-$1,504	2003$			**EPA 2003a**
ICI Boilers-Coal--Low Sulfur	Flue Gas Desulfurization	90	$461-$1,326	2003$			**EPA 2003a**
ICI Boilers-Residual Oil	Flue Gas Desulfurization	90	$2,295-$3,500	1999$	The cost effectiveness is a function of boiler capacity. For boilers below 100 million BTU the cost per ton is $4524, for 100-250 million BTU the cost per ton is 3489 and for larger than 250 million BTU the cost per ton is $2295.		**EPA 2003a**
ICI Boiler - Distillate Oil	Reduce sulfur content from 2500 ppm to 500 ppm	80	2,350	1999$	Developmental measure from PM NAAQS RIA	80% PM2.5 co-benefit	**EPA 2006a**
Inorganic Chemical Manufacture Operations--Carbon Black Production	Reduce Sulfur in Feedstock	up to 50?	Not known		EPA information indicates US facilities use feedstock with about 4% sulfur, while European facilities use feedstock with about 2 % sulfur.		**EPA 2006b**

Potential Stationary and Area Source Measures for SO2

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Iron and Steel--Coke Ovens	Coke oven gas desulfurization	90+					**Pechan 2006**
Oil and Gas Production--Process heaters	Flue Gas Desulfurization	90					**EPA 1981**
Petroleum refining--catalytic and thermal cracking units	Catalyst additives	35 - 50	$ 1096 - 1889		This type of SO2 control is required in some refinery industry cases and settlements		**MARAMA 2006,** Eagleson et al., 2004,
Petroleum refining--catalytic and thermal cracking units	Wet gas scrubbers	95 - 99.9	$ 499 - 880	2004$	This type of SO2 control is required in some refinery industry cases and settlements		**MARAMA 2006,** Eagleson et al., 2004,
Petroleum refining -- catalytic and thermal cracking units	Feed hydrotreatment	Not given	Not given				**MARAMA, 2006**
Petroleum refining--flares	Process changes to reduce flaring	Variable depending on suite of measures selected	Variable depending on suite of measures selected				**MARAMA, 2006**
Petroleum refining--process heaters	Scrubbing: Wet Scrubbers, Spray Dry Scrubbers, Dry Scrubbers	90 - 99.9	$ 7674 - 45, 384				**MARAMA, 2006**
Petroleum refining--process heaters burning residual oil	Eliminate the combustion of fuel oil (>0.05% sulfur by weight)	>95	Not given				**MARAMA, 2006**
Petroleum refining--sulfur recovery units	Increased recovery efficiency, tail gas treatment such that H2 S content of fuels is meets 0.10 gr/dscf (162 ppm) limit	variable depending on current recovery efficiency	Variable depending on current recovery efficiency			variable based on current recovery efficiency	**MARAMA, 2006**
Primary aluminum plants	Addition of scrubbers to control system for captured emissions from anode bake furnaces						**EPA, 2006b**
Primary aluminum plants	Use of coke and pitch with lower sulfur content						**EPA, 2006b**

Potential Stationary and Area Source Measures for SO2

Source category	**Emissions reduction measure**	**Control efficiency (%)**	**Cost effectiveness ($/ton reduced)**	**Cost Year**	**Notes/caveats**	**Other pollutants controlled**	**References for more information**
Primary Lead Smelters - Sintering	Dual Absorption Acid Plant	90					**EPA 1981**
Primary Zinc Smelters - Sintering	Dual Absorption Acid Plant	90					**EPA 1981**
Pulp and Paper--acid sulfite pulping	Alkaline scrubber						**STAPPA/ALAPCO 2006**
Pulp and Paper--acid sulfite pulping	Raise pH of digester before releasing excess gas						**STAPPA/ALAPCO 2006**
Pulp and paper--recovery furnaces	Reduce sulfur content of black liquor before combustion						**AWMA 2000**
Pulp and paper--recovery furnaces	Regulate temperatures in the furnace to minimize SO2 formation						**STAPPA/ALAPCO 2006**
Residential fuel combustion--Home Heating Oil	Reduce sulfur content from 2500 ppm to 500 ppm	80	$2,350	1999$	Some areas currently have 500 ppm limits.		**NESCAUM 2005**
Sulfur Recovery Plants at Elemental Sulfur Plants, Oil and Gas Production, and other sulfur recovery plants not located at refineries	Increased recovery efficiency, tail gas treatment	Variable depending on current recovery efficiency	Variable depending on current recovery efficiency				**EPA 2002**
Sulfuric Acid Plants	Increased recovery efficiency	Variable depending on current recovery efficiency	Variable depending on current recovery efficiency				**Pechan 2006**
Utility Boilers	* (see footnote)						

* This document does not address SO2 and NOx controls for EGU. These controls are relatively well known and are the subject of policy discussions among states, multi-state bodies and the EPA.

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Agricultural Burning	Seasonal Ban (Ozone Season Daily)	OSD control efficiency is 100%					**Pechan 1997 and Pechan 2006**
Ammonia - Natural Gas - Fired Reformers	Low NOx Burner	50	$820	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Ammonia - Natural Gas - Fired Reformers	Low NOx Burner + Flue Gas Recirculation	60	$2,560	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Ammonia - Natural Gas - Fired Reformers	Oxygen Trim + Water Injection	65	$680	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Ammonia - Natural Gas - Fired Reformers	Selective Catalytic Reduction (SCR)	80	$2,230	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Ammonia - Natural Gas - Fired Reformers	Selective Non-Catalytic Reduction (SNCR)	50	$3,780	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Ammonia Products; Feedstock Desulfurization	Low NOx Burner + Flue Gas Recirculation	60	$2,560	1990$			**EPA 1994a, EPA 2002, Pechan 1998, Pechan 2001**
Asphalt Plant Manufacture	Low NOx Burner + Flue Gas Recirculation	30-50					
Asphaltic Conc; Rotary Dryer; Conv Plant	Low NOx Burner	50	$2,200	1990$			**EPA 1993, EPA 2002, Pechan 1998a**
By-Product Coke Manufacturing; Oven Underfiring	Selective Non-Catalytic Reduction (SNCR)	60	$1,640	1990$			**EPA 1994, EPA 2002, Pechan 1998a, Pechan 2001**
Cement Kilns	Biosolids injection	23	$310	1999$			**Pechan 2006**
Cement Kilns	Changing feed composition						**LADCO 2005**
Cement Kilns	Low NOx Burner	27-40	$166-$1,299	2004$			**LADCO 2005**
Cement Kilns	Mid-Kiln Firing	33-41	-$460 to $730	2004$			**LADCO 2005**
Cement Kilns	Process control systems						**LADCO, 2005**
Cement Kilns	Selective Catalytic Reduction (SCR)	80	$3,370	1999$	The STAPPA/ALAPCO report presents SCR data from different sources that indicate control efficiencies from 31-95 % for SCR. Corresponding cost per ton ranges are 500-2,700 dollars per ton (2000 and 2002 dollars).		**Pechan 2006**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Cement Kilns	SNCR-ammonia based	50	$850	1999$			**EC/R 2000**
Cement Kilns	SNCR-urea based	50	$770	1999$			**EC/R 2000**
Ceramic Clay Manufacturing; Drying - Small Sources	Low NOx Burner	50	$2,200	1990$			**EPA 2002 and Pechan 1998a**
Coal Cleaning-Thrml Dryer; Fluidized Bed - Small Sources	Low NOx Burner	50	$200-$1,000	2003$			**Reaction Engineering International and Energy & Environmental Strategies**
Combustion Turbine Aeroderivative Gas Turbines	Water Injection	40	44,000	2005$			**NJDEP 2005**
Combustion Turbines - Jet Fuel, Oil	Selective Catalytic Reduction (SCR) + Water Injection	90	$2,300	1990$			**EPA 2002**
Combustion Turbines - Jet Fuel, Oil	Water Injection	68	$1,290	1990$			**EPA 2002**
Combustion Turbines - Natural Gas	Dry Low NOx Combustors	84	$100 (large) $490 (small)	1990$			**EPA 2002**
Combustion Turbines - Natural Gas	Selective Catalytic Reduction (SCR) + Low NOx Burner (LNB)	95	$2,570	1990$	Cost effectivness is $19,120 per ton NOx reduced from RACT baseline		**EPA 2002**
Combustion Turbines - Natural Gas	Selective Catalytic Reduction (SCR) + Steam Injection	95	$2,010	1990$	Cost effectiveness is $8,960 per ton NOx reduced from RACT baseline		**EPA 2002**
Combustion Turbines - Natural Gas	Selective Catalytic Reduction (SCR) + Water Injection	95	$2,730	1990$			**EPA 2002**
Combustion Turbines - Natural Gas	Steam Injection	80	$1,040	1990$			**Pechan 1998a and Pechan 2001**
Combustion Turbines - Natural Gas	Water Injection	76	$1,510	1990$			**Pechan 1998a and Pechan 2001**
Commercial/Institutional - Natural Gas	Water Heaters + LNB Space Heaters	7	$1,230	1990$			**SCAQMD 1996**
Commercial/Institutional Incinerators	Selective Non-Catalytic Reduction (SNCR)	45	$1,130	1990$			**EPA 2002**
Conv Coating of Prod; Acid Cleaning Bath	Low NOx Burner	50	$2,200	1990$			**EPA 2002**
Fiberglass Manufacture; Textile-Type; Recuperative Furnaces	Low NOx Burner	40	$1,690	1990$			**EPA 2002**

Potential Stationary and Area Source Measures for NOx

Source category	**Emissions reduction measure**	**Control efficiency (%)**	**Cost effectiveness ($/ton reduced)**	**Cost Year**	**Notes/caveats**	**Other pollutants controlled**	**References for more information**
Fluid Catalytic Cracking Units	Low NOx Burner + Flue Gas Recirculation	55	$3,190	1990$	Cost effectiveness is estimated to be $1,430 per ton NOx reduced from RACT baseline.		**EPA 2002**
Fuel Fired Equipment - Process Heaters	Low NOx Burner + Flue Gas Recirculation	50	$570	1990$			**EPA 2002**
Fuel Fired Equipment; Furnaces; Natural Gas	Low NOx Burner	50	$570	1990$			**EPA 2002**
Glass Manufacturing - Containers	Cullet Preheat	25	$490	1990$			**Pechan 1998a**
Glass Manufacturing - Containers	Electric Boost	10	$7,150	1990$			**Pechan 1998a**
Glass Manufacturing - Containers	Low NOx Burner	40	$1,690	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Containers	OXY-Firing	85	$4,590	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Containers	Selective Catalytic Reduction (SCR)	75	$2,200	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Containers	Selective Non-Catalytic Reduction (SNCR)	40	$1,770	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Flat Glass	Low NOx Burner	40	$700	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Flat Glass	OXY-Firing	85	$1,900	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Flat Glass	Selective Catalytic Reduction (SCR)	75	$710 (large), $3,370 (small)	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Flat Glass	Selective Non-Catalytic Reduction (SNCR)	40	$740	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	Cullet Preheat	25	$810	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	Electric Boost	10	$2,320 - $8,760	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	Low NOx Burner	40	$1,500	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	OXY-Firing	85	$3,900	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	Selective Catalytic Reduction (SCR)	75	$2,530	1990$			**EPA 2002 and Pechan 1998a**
Glass Manufacturing - Pressed Glass	Selective Non-Catalytic Reduction (SNCR)	40	$1,640	1990$			**EPA 1994c and Pechan 2006**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
IC Engines - Gas	Selective Catalytic Reduction (SCR)	90	2,769	1990$			**EPA 1993b**
IC Engines - Gas, Diesel, LPG	Ignition Retard	25	$770	1990$			**EPA 1993b**
IC Engines - Gas, Diesel, LPG	Selective Catalytic Reduction (SCR)	80	2,340	1990$			**EPA 1993b**
IC Engines - Gas--Lean burn	Low emission combustion	87	$422	1993$	The cost effectiveness is in ozone season dollars per ton.		**Pechan 2000**
IC Engines-Gas--Rich burn	Non-Selective Catalytic Reduction	90	342	1993$	The cost effectiveness is in ozone season dollars per ton.		**Pechan 2000**
ICI Boilers-Coal	Selective Catalytic Reduction (SCR)	80	$876-$2,141	2003$			**EPA 2003**
ICI Boilers-Coal	Selective Non-Catalytic Reduction (SNCR)	40	$1,285-$2,073	2003$			**EPA 2003**
ICI Boilers-Coal-bituminous	Low NOx Burner plus Overfire Air	51	$392-$1,239	2003$			**EPA 2003**
ICI Boilers-Coal-subbituminous	Low NOx Burner	51	$256-$850	2003$	The cost effectiveness is for boilers operating at capacity factors in the range of 50-83 percent. Unit sizes range from 100 million BTU/hr (hughest cost per ton) to 1000 million BTU/Hr (lowest cost per ton)		**EPA 2003**
ICI Boilers-Coal-subbituminous	Low NOx Burner plus Overfire Air	65	$306-$972	2003$			**EPA 2003**
ICI Boilers-Gas	LNB plus Overfire air plus gas recirculation	80	$368-$1,278	2003$			**EPA 2003**
ICI Boilers-Gas	Low NOx Burner plus Overfire Air	60	$280-$1,052	2003$			**EPA 2003**
ICI Boilers-Gas	Selective Catalytic Reduction (SCR)	80	986-2,933	2003$			**EPA 2003**
ICI Boilers-Gas	Selective Non-Catalytic Reduction (SNCR)	40	$280-$1,052	2003$			**EPA 2003**
ICI Boilers-Oil	Low NOx Burner plus Overfire Air	30-50	$306-$1,052	2003$			**EPA 2003**
ICI Boilers-Oil	Selective Catalytic Reduction (SCR)	80	760-2,014	2003$			**EPA 2003**
ICI Boilers-Oil	Selective Non-Catalytic Reduction (SNCR)	40	$1,485-$2,367	2003$			**EPA 2003**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Internal Combustion Engines - Gas	Air/Fuel + Ignition Retard	30	$460	1990$			**EPA 1993b**
Internal Combustion Engines - Gas	Air/Fuel Ratio Adjustment	20	$380	1990$			**EPA 1993b**
Internal Combustion Engines - Gas	Ignition Retard	20	$550	1990$			**EPA 1993b**
Iron & Steel Mills - Annealing	Low NOx Burner + Selective Catalytic Reduction	90	$4,080	1990$	The cost effectiveness is $3,720 per ton NOx reduced from RACT baseline		**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Annealing	Low NOx Burner + Selective Catalytic Reduction	80	$1,720	1990$			**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Annealing	Selective Catalytic Reduction (SCR)	85	$3,830	1990$			**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Annealing	Selective Non-Catalytic Reduction (SNCR)	60	$1,640	1990$			**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Annealing, Galvanizing, Reheating	Low NOx Burner	50 - 65	$300 -$570	1990$			**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Annealing, Galvanizing, Reheating	Low NOx Burner + Flue Gas Recirculation	60 - 77	$380-$750	1990$			**EPA 2002 and Pechan 1998a**
Iron & Steel Mills - Reheating	Low Excess Air	13	$1,320	1990$			**EPA 2002 and Pechan 1998a**
Iron Production; Blast Furnaces; Blast Heating Stoves	Low NOx Burner + Flue Gas Recirculation	77	$380	1990$			**EPA 2002 and Pechan 1998a**
Lime Kilns	Low NOx Burner	30	$560	1999$			**EPA 1994**
Medical Waste Incinerators	Selective Non-Catalytic Reduction (SNCR)	45	$4,510	1990$			**EPA 2002 and Pechan 1998a**
Municipal Waste Combustors	Selective Non-Catalytic Reduction (SNCR)	45	$1,130	1990$			**EPA 2002 and Pechan 1998a**
Natural Gas Production; Compressors	Selective Catalytic Reduction (SCR)	20	$1,650	1990$			**EPA 2002 and Pechan 1998a**
Nitric Acid Manufacturing	Extended Absorption	95	$480	1990$			**EPA 2002 and Pechan 1998a**
Nitric Acid Manufacturing	Non-Selective Catalytic Reduction	98	$550	1990$			**EPA 2002 and Pechan 1998a**
Nitric Acid Manufacturing	Selective Catalytic Reduction (SCR)	97	$590	1990$			**EPA 2002 and Pechan 1998a**
Open Burning	Episodic Ban during ozone alert days	Daily control efficiency is 100%					**Pechan 2006**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Process Heaters - Distillate and Residual Oil	Low NOx Burner + Flue Gas Recirculation	34-48	$3,500-$4,500	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate and Residual Oil	Low NOx Burner + Selective Catalytic Reduction	75	$2,300	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate and Residual Oil	Selective Catalytic Reduction (SCR)	75	5350-9230	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate and Residual Oil	Selective Non-Catalytic Reduction (SNCR)	60	$1,930-$3,180	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate and Residual Oil	Ultra Low NOx Burner	74	$1,290-$2,140	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate Oil	Low NOx Burner	37 - 45	$2,500 - $3,740	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate Oil	Low NOx Burner + Selective Catalytic Reduction	92	$9,120	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Distillate Oil	Low NOx Burner + Selective Non-Catalytic Reduction (SNCR)	78	$3,620	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG	Selective Catalytic Reduction (SCR)	75	$5350-$12,040	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Low NOx Burner	45-50	$2,200 -$3,740	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Low NOx Burner + Flue Gas Recirculation	48-55	$3,200-$4,200	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Low NOx Burner + Selective Catalytic Reduction	88- 92	$9,120-$11,500	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Low NOx Burner + Selective Catalytic Reduction	80	$2,320-$3,620	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Selective Non-Catalytic Reduction (SNCR)	60	$1,930-$3,180	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - LPG, NG, Process Gas	Ultra Low NOx Burner	75	$1,290-$2,140	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Process Gas	Low NOx Burner + Selective Non-Catalytic Reduction (SNCR)	80	$3,520	1990$			**EPA 2002 and Pechan 1998a**
Process Heaters - Residual Oil	Low NOx Burner + Selective Catalytic Reduction	90	$5,420	1990$			**EPA 2002 and Pechan 1998a**
Reciprocating Internal Combustion Engines - Oil -All	Selective Catalytic Reduction (SCR)	80	$1,066	1993$			**Pechan 2000**
Reciprocating Internal Combustion Engines-Oil-All	Ignition retard	25	$770	1999$			**Pechan 2006**
Residential Natural Gas	Water Heater + LNB Space Heaters	7	$1,230				**Pechan 2006**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Rich-Burn Stationary Reciprocating Internal Combustion Engines (RICE)	Non-Selective Catalytic Reduction	90	342	1990$		VOC and CO emissions are also reduced.	**EPA 1993**
Sand/Gravel; Dryer	Low NOx Burner + Flue Gas Recirculation	55	$3,190	1990$			**EPA 2002 and Pechan 1998a**
Secondary Aluminum Production; Smelting Furnaces	Low NOx Burner	50	$570	1990$			**EPA 2002 and Pechan 1998a**
Solid Waste Disposal; Government	Selective Non-Catalytic Reduction (SNCR)	45	$1,130	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Distillate Oil	Low NOx Burner	50	$1,180	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Distillate Oil	Low NOx Burner + Flue Gas Recirculation	60	$2,500	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Distillate Oil	Selective Catalytic Reduction (SCR)	80	$2,780	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Distillate Oil	Selective Non-Catalytic Reduction (SNCR)	50	$4,640	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Natural Gas	Low NOx Burner	50	$820	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Natural Gas	Low NOx Burner + Flue Gas Recirculation	60	$2,650	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Natural Gas	Oxygen Trim + Water Injection	65	$680	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Natural Gas	Selective Catalytic Reduction (SCR)	80	$2,860	1990$			**EPA 2002 and Pechan 1998a**
Space Heaters - Natural Gas	Selective Non-Catalytic Reduction (SNCR)	50	$3,870	1990$			**EPA 2002 and Pechan 1998a**
Starch Manufacturing; Combined Operation	Low NOx Burner + Flue Gas Recirculation	55	$3,190	1990$			**EPA 2002 and Pechan 1998a**
Steel Foundries; Heat Treating	Low NOx Burner	50	$570	1990$			**EPA 2002 and Pechan 1998a**
Steel Production; Soaking Pits	Low NOx Burner + Flue Gas Recirculation	60	$750	1990$			**EPA 2002 and Pechan 1998a**
Sulfate Pulping - Recovery Furnaces	Low NOx Burner	50	$820	1990$			**EPA 2002 and Pechan 1998a**
Sulfate Pulping - Recovery Furnaces	Low NOx Burner + Flue Gas Recirculation	60	$2,560	1990$			**EPA 2002 and Pechan 1998a**
Sulfate Pulping - Recovery Furnaces	Oxygen Trim + Water Injection	65	$680	1990$			**EPA 2002 and Pechan 1998a**
Sulfate Pulping - Recovery Furnaces	Selective Catalytic Reduction (SCR)	80	$2,230	1990$			**EPA 2002 and Pechan 1998a**
Sulfate Pulping - Recovery Furnaces	Selective Non-Catalytic Reduction (SNCR)	50	$3,870	1990$			**EPA 2002 and Pechan 1998a**

Potential Stationary and Area Source Measures for NOx

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Surface Coat Oper; Coating Oven Htr; Nat Gas	Low NOx Burner	50	$2,200	1990$			**EPA 2002 and Pechan 1998a**
Utility Boilers*							

* This document does not address SO2 and NOx controls for EGU. These controls are relatively well known and are the subject of policy discussions among states, multi-state bodies and the EPA.

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Potential Stationary and Area Source Measures References

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Onroad PM Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
School Bus	Diesel Retrofit - Diesel Oxidation Catalysts	20	12000 - 49100	Applies to 1990-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
School Bus	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	12400 - 50500	Applies to 1995-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 6 & 7 HDDVs	Diesel Retrofit - Diesel Oxidation Catalysts	20	27600 - 67900	Applies to 1990-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 6 & 7 HDDVs	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	28400 - 69900	Applies to 1995-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 8B HDDV	Diesel Retrofit - Diesel Oxidation Catalysts	20	11100 - 40600	Applies to 1990-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 8B HDDV	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	12100 - 44100	Applies to 1995-2006 model years	VOC, CO	EPA 2006b, EPA 2006d, EPA 2006
HDDVs	Diesel Retrofit - Active Diesel Particulate Filter	80 - 90+			VOC, CO	STAPPA/ALAPCO 2006, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Lean NOx Catalyst and Diesel Particulate Filter	85		Applies to 1993 - 2003 model years; needs 15 ppm sulfur diesel	NOX	CARB 2006a, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Exhaust Gas Recirculation/Diesel Particulate Filter	85		Applies to specific engine families from 1998-2002 model years; needs 15 ppm sulfur diesel	NOX	CARB 2006a, EPA 2006
HDDVs	Diesel Retrofit - Flow Through Filter	50 - 76		Applies to 1991 - 2002 model years; needs 15 ppm sulfur diesel or CARB diesel	VOC, CO	STAPPA/ALAPCO 2006; CARB 2006a, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Diesel Oxidation Catalysts + Flow Through Filters	50		Applies to 1988 - 1993 model years; needs 15 ppm sulfur diesel		CARB 2006a, EPA 2006
HDDVs	Diesel Retrofit - Closed Crankcase Ventilation	10				EPA 2006e, EPA 2006
HDDVs	Diesel Retrofit - Closed Crankcase Filter System	5 - 10				STAPPA/ALAPCO 2006, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Diesel Oxidation Catalyst + Crankcase Filter	25		Applies to 1988-2002 model years; needs 15 ppm sulfur diesel		CARB 2006a, EPA 2006
Class 5 and above HDDVs and buses	Replacement	90 - 98		Applies to 1990-2006 model years	NOX, VOC	EPA 2006d
Class 8 HDDVs	Eliminate Long Duration Idling with Truck Stop Electrification	3.4	0	Upfront capital costs fully recovered by fuel savings	NOX, VOC, SO2, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Eliminate Long Duration Idling with Mobile Idle Reduction Technologies	3.4	0	Upfront capital costs fully recovered by fuel savings	NOX, VOC, SO2, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Intermodal - shift of transportation of goods from truck to rail transport	1.0	0	Would result in a 0.3-0.4% increase in all pollutants from locomotive and rail SCCs; represents a 1% shift from truck-only transport to rail	NOX, SO2, NH3, VOC	EPA 2006d
HDDVs	Alternative Fuel - Oxygenated Diesel	0 - 50		Oxygenated with ethanol; Nox emissions likely to increase	VOC, CO, CO2	STAPPA/ALAPCO 2006

Onroad PM Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
HDDVs	Alternative Fuel - Fuel-borne Catalyst	0 - 50			NOX, VOC, CO	STAPPA/ALAPCO 2006
Class 8 HDDVs	Alternative Fuel - Lubrizol PuriNOX	50		Applies to 1988 - 2003 model years	NOX	CARB 2006a
HDDVs	Alternative Fuel - Emulsified Diesel	16 - 58		Increases VOC, CO	NOX	EPA 2006e; STAPPA/ALAPCO 2006
HDDVs	Alternative Fuel - Biodiesel	10 - 12		Increases NOX	VOC, CO	EPA 2006e; STAPPA/ALAPCO 2006
LDGVs and LDGTs	Best Workplaces for Commuters-all measures combined			Reductions based on the following measures: Regional Rideshare, Vanpool Programs, Park-and-ride lots, Regional TDM, Employer trip reduction programs;	NOX, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Convert State and Large Corporate Fleets to Hybrid and/or alternate fuel				VOC, NOX, SO2	NJDEP 2005b
LDGVs and LDGTs	MPG/Emissions Requirements for Large Fleets				VOC, NOX, SO2	NJDEP 2005b
LDGVs and LDGTs	Registration fee based on VMT				VOC, NOX, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Shuttles in Structured Communities				VOC, NOX, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Vehicle Charging Stations				VOC, NOX, SO2	NJDEP 2005b
LDGVs, LDGTs, HDGVs, MCs	Increase fuel tax				VOC, NOX, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Expansion of Bike/hiking trails				VOC, NOX, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Ban drive-through windows at fast food restaurants and banks				VOC, NOX, SO2	NJDEP 2005b
HDDVs	Voluntary Programs - National Clean Diesel Campaign				NOX	EPA 2005
HDDVs	Voluntary Programs - SmartWay Transport Partnership				NOX	EPA 2005
HDDVs	Driver incentive/training program to reduce idling				VOC, NOX, SO2	NJDEP 2005a
HDDVs	Hybrid Power Train Technology			Provides fuel savings of 10% - 15%. Being tested by UPS and FedEx.	VOC, NOX, SO2	NJDEP 2005a
HDDVs and Diesel Buses	Heavy-Duty Vehicle Inspection Program			NOx benefits result from reflashing vehicles subject to the heavy duty diesel consent decree	NOX	CARB 2006b, NJDEP 2005a
HDDV Fleet and Diesel Bus Fleet	Periodic Smoke Inspection Program			NOx benefits result from reflashing vehicles subject to the heavy duty diesel consent decree	NOX	CARB 2006b

Onroad PM Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
HDDVs	Incentive Programs (e.g., Carl Moyer Program)				NOX	CARB 2006b
LDGVs and LDGTs	Incentives for hybrids and other ULEV, SULEV, ZEV vehicles				VOC, NOX, SO2	CARB 2006b
All Highway Vehicles	Smoking Vehicle Hotline				NOX, VOC	CARB 2006b
On-road fugitive dust						
Paved Roads	Street Sweeping	Effectiveness varies with frequency				
Paved Roads	Require 4 foot paved shoulders		(all new paved roads) $13,800 - $554,000, (50% of existing paved roads) $7,290-$11,300 - per ton of PM10	2002$		San Joaquin Valley UAPCD 2003
Paved Roads	Require wind- and water-borne deposition to be removed within 24 hours of discovery		$2,850 per ton PM10 reduced	2002$		San Joaquin Valley UAPCD 2003
Unpaved Roads	Chemical Stabilization/ Dust Suppressant Application	25	$2,753 per ton PM removed	1990$		EPA 1986
Unpaved Roads	Implement rules to limit visible dust emissions to 20% opacity on unpaved parking areas receiving up to 100 trips per day		$5,230-$30,500 per ton PM10	2002$		San Joaquin Valley UAPCD 2003
Unpaved Roads	Limit max speed on unpaved roads to 25 mph		$1,080 per ton PM10	2002$		San Joaquin Valley UAPCD 2003
Unpaved Roads	Pave unpaved roads and unpaved parking lots	25	$2,160-$5,920 per ton PM10 (2002$)	2002$		San Joaquin Valley UAPCD 2003
Unpaved Roads	Require paving, 4 inches gravel, or dust suppressant at special event parking		$5,980-$63,200 per ton PM10	2002$		San Joaquin Valley UAPCD 2003

Notes:

LDGV=Light-duty Gasoline Vehicle
LDGT=Light-duty Gasoline Truck
HDGV=Heavy-duty Gasoline Vehicle
MC=Motorcycle
LDDV=Light-duty Diesel Vehicle
LDDT=Light-duty Diesel Truck
HDDV=Heavy-duty Diesel Vehicle

Onroad SO2 Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
Class 8 HDDVs	Eliminate Long Duration Idling with Truck Stop Electrification	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, NOX, VOC, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Eliminate Long Duration Idling with Mobile Idle Reduction Technologies	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, NOX, VOC, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Intermodal - shift of transportation of goods from truck to rail transport	1.0	0	Would result in a 0.3-0.4% increase in all pollutants from locomotive and rail SCCs; represents a 1% shift from truck-only transport to rail	PM, NOX, NH3, VOC	EPA 2006d
LDGVs and LDGTs	Best Workplaces for Commuters-all measures combined	0.4-1.0		Reductions based on the following measures: Regional Rideshare, Vanpool Programs, Park-and-ride lots, Regional TDM, Employer trip reduction programs; control efficiency depends on penetration--0.4% reduction at 10% penetration and 1.0% reduction at 25% penetration	PM, NOX, VOC, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Convert State and Large Corporate Fleets to Hybrid and/or alternate fuel				VOC, NOX, PM	NJDEP 2005b
LDGVs and LDGTs	MPG/Emissions Requirements for Large Fleets				VOC, NOX, PM	NJDEP 2005b
LDGVs and LDGTs	Fee based on VMT				VOC, NOX, PM, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Shuttles in Structured Communities				VOC, NOX, PM, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Vehicle Charging Stations				VOC, NOX, PM	NJDEP 2005b
LDGVs, LDGTs, HDGVs, and MCs	Increase fuel tax				VOC, NOX, PM, NH3	NJDEP 2005b
LDGVs and LDGTs	Expansion of Bike/hiking trails				VOC, NOX, PM, NH3	NJDEP 2005b
LDGVs and LDGTs	Ban drive-through windows at fast food and banks				VOC, NOX, PM	NJDEP 2005b
HDDVs	Driver incentive/training program to reduce idling				VOC, NOX, PM	NJDEP 2005a
HDDVs	Hybrid Power Train Technology			Provides fuel savings of 10% - 15%. Being tested by UPS and FedEx.	VOC, NOX, PM	NJDEP 2005a
LDGVs and LDGTs	Incentives for hybrids and other ULEV, SULEV, ZEV vehicles				VOC, NOX, PM	CARB 2006b

Notes:

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Onroad NOx Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
HDDVs	Diesel Retrofit - NOX Reducing Catalyst	20 - 30				STAPPA/ALAPCO 2006, EPA 2006
HDDVs	Diesel Retrofit - NOX Adsorber	90+			PM, VOC, CO	STAPPA/ALAPCO 2006, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Selective Catalytic Reduction (SCR)	70 to 99	3000 - 15000	Cost effectiveness based on pre-1989 to 2006 model years		ENVIRON 2006, EPA 2006
Class 5 and above HDDVs and Diesel Buses	Replacement	90 - 97		Applies to 1990-2006 model years	PM, VOC	EPA 2006d
Class 8 HDDVs	Eliminate Long Duration Idling with Truck Stop Electrification	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, VOC, SO2, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Eliminate Long Duration Idling with Mobile Idle Reduction Technologies	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, VOC, SO2, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Intermodal - shift of transportation of goods from truck to rail transport	1.0	0	Would result in a 0.3-0.4% increase in all pollutants from locomotive and rail SCCs; represents a 1% shift from truck-only transport to rail	PM, SO2, NH3, VOC	EPA 2006d
Class 8 HDDVs	Diesel Retrofit - Lean NOx Catalyst and Diesel Particulate Filter	25		Applies to 1993 - 2003 model years; needs 15 ppm sulfur diesel	PM	CARB 2006a, EPA 2006
Class 8 HDDVs	Diesel Retrofit - Exhaust Gas Recirculation/Diesel Particulate Filter	40		Applies to specific engine families from 1998-2002 model years; needs 15 ppm sulfur diesel	PM	CARB 2006a, EPA 2006
Class 8 HDDVs	Alternative Fuel - Lubrizol PuriNOX	15		Applies to 1988 - 2003 model years	PM	CARB 2006a
LDGVs and LDGTs	Best Workplaces for Commuters-all measures combined	0.4-1.0	19200	Average cost effectiveness based on the following measures: Regional Rideshare, Vanpool Programs, Park-and-ride lots, Regional TDM, Employer trip reduction programs; control efficiency depends on penetration--0.4% reduction assumes 10% penetration and 1.0% reduction assumes 25% reduction	PM, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Best Workplaces for Commuters - Regional Rideshare		1200 - 16000*(see notes)	Control efficiency depends on penetration; Cost effectiveness based on weighted sum of Nox and VOC reductions (i.e., total cost/((VOC*1)+(NOx*4))	PM, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Best Workplaces for Commuters - Vanpool Programs		5200 - 89000*(see notes)	Control efficiency depends on penetration; Cost effectiveness based on weighted sum of Nox and VOC reductions (i.e., total cost/((VOC*1)+(NOx*4))	PM, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b

Onroad NOx Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
LDGVs and LDGTs	Best Workplaces for Commuters - Park-and-ride lots		8600 - 70700*(see notes)	Control efficiency depends on penetration; Cost effectiveness based on weighted sum of Nox and VOC reductions (i.e., total cost/((VOC*1)+(NOx*4))	PM, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Best Workplaces for Commuters - Regional Transportation Demand Management (TDM)		2300 - 33200*(see notes)	Control efficiency depends on penetration; Cost effectiveness based on weighted sum of Nox and VOC reductions (i.e., total cost/((VOC*1)+(NOx*4))	PM, VOC, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs and LDGTs	Best Workplaces for Commuters - Employer trip reduction programs		5800 - 175500*(see notes)	Control efficiency depends on penetration; Cost effectiveness based on weighted sum of Nox and VOC reductions (i.e., total cost/((VOC*1)+(NOx*4))	PM, VOC, SO2, NH3, CO	EPA 2006d, 2005b
HDDVs	Diesel Retrofit - Lean NOX Catalyst	5 - 40	6000 - 28000			ENVIRON 2006, EPA 2006e, EPA 2006
HDDVs	Diesel Retrofit - Exhaust Gas Recirculation	40 - 50				EPA 2006e, EPA 2006
HDDVs	Alternative Fuel - Emulsified Diesel	9 - 20		Increases VOC, CO	PM	EPA 2006e
LDGVs, LDGTs, HDGVs, and MCs	Federal Reformulated Gasoline (RFG)	7			VOC, CO	Pechan 2006, EPA 1999
LDGVs and LDGTs	High Enhanced I/M Program	0.4 - 13.4		Reduction is based on emissions from entire fleet	VOC, CO	Pechan 2006
HDDVs	Alternative Fuel - Fuel-borne Catalyst	0 - 10			PM, VOC, CO	STAPPA/ALAPCO 2006
LDGVs and LDGTs	Repair assistance for low-income owners of older poorly maintained vehicles				VOC	NJDEP 2005b
LDGVs and LDGTs	Convert State and Large Corporate Fleets to Hybrid and/or alternate fuel				VOC, PM, SO2	NJDEP 2005b
LDGVs and LDGTs	MPG/Emissions Requirements for Large Fleets				VOC, PM, SO2	NJDEP 2005b
LDGVs and LDGTs	Fee based on VMT				VOC, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Shuttles in Structured Communities				VOC, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Vehicle Charging Stations				VOC, PM, SO2	NJDEP 2005b
LDGVs, LDGTs, HDGVs, and MCs	Increase fuel tax				VOC, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Expansion of Bike/hiking trails				VOC, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Ban drive-through windows at fast food and banks				VOC, PM, SO2	NJDEP 2005b

Onroad NOx Control Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
HDDVs	Voluntary Programs - National Clean Diesel Campaign				PM	EPA 2005
HDDVs	Voluntary Programs - SmartWay Transport Partnership				PM	EPA 2005
HDDVs	Driver incentive/training program to reduce idling				VOC, PM, SO2	NJDEP 2005a
HDDVs	Hybrid Power Train Technology			Provides fuel savings of 10% - 15%. Being tested by UPS and FedEx.	VOC, PM, SO2	NJDEP 2005a
All Highway Vehicles	Intelligent Transport System - Speed Limit Restriction (65 mph)					TCEQ2006
HDDVs and Diesel Buses	Heavy-Duty Vehicle Inspection Program			NOx benefits result from reflashing vehicles subject to the heavy duty diesel consent decree	PM	CARB 2006b, NJDEP 2005a
HDDV Fleet, and Diesel Bus Fleet	Periodic Smoke Inspection Program			NOx benefits result from reflashing vehicles subject to the heavy duty diesel consent decree	PM	CARB 2006b
HDDVs	Software Upgrade for Diesel Trucks ("Chip Reflash")		1800 - 2500	Rebuild kits are free to any truck operator requesting one from truck manufacturer as a result of the Consent Decree with EPA. Each kit costs about $20-$30/vehicle.		CARB 2006b, OTC 2006
HDDVs	Incentive Programs (e.g., Carl Moyer Program)				PM	CARB 2006b
LDGVs and LDGTs	Incentives for hybrids and other ULEV, SULEV, ZEV vehicles				VOC, PM, SO2	CARB 2006b
All Highway Vehicles	Smoking Vehicle Hotline				VOC, PM	CARB 2006b

Notes:

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LDDT=Light-duty Diesel Truck
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Onroad Control Measures References

Key For Tables	Complete Reference	URL
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CARB 2006b	California Air Resources Board, "ARB Programs," updated May 4, 2006	http://www.arb.ca.gov/html/programs.htm
ENVIRON 2006	ENVIRON International Corporation, "Evaluation of Candidate Mobile Source Control Measures", Final Report, prepared for Lake Michigan Air Directors Consortium, 2250 E. Devon Ave., #250, Des Plaines, IL 60018, February 28,	http://www.ladco.org/reports/rpo/Regional%20Air%20Quality/LADCO%20Control%20Report_Final.pdf
EPA 1999	U.S. Environmental Protection Agency, Office of Air and Radiation, "Phase II Reformulated Gasoline: The Next Major Step Toward Cleaner Air", EPA420-	http://www.epa.gov/OMSWWW/rfg/f99042.pdf
EPA 2004	Guidance for Quantifying and Using Long DurationTruck Idling Emission Reductions In State Implementation Plans and Transportation Conformity, EPA420-B-04-001, January 2004.	
EPA 2005	Draft list of potential RACT and RACM from PM rule preamble (see EPA websites on verified retrofit technologies)	http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm
EPA 2005b	Guidance for Quantifying and Using Emissions Reductions from Best Workplaces for Commuter Programs in State Implementation Plans and Transportation Conformity Determinations, EPA420-B-05-016, October 2005,	
EPA 2006	Diesel Retrofits: Quantifying and Using Their Benefits in SIPs and Conformity, EPA420-B-06-005, June 2006.	
EPA 2006b	U.S. Environmental Protection Agency, Office of Transportation and Air Quality, "Diesel Retrofit Technology, An Analysis of the Cost-Effectiveness of Reducing Particulate Matter Emissions from Heavy-Duty Diesel Engines	http://www.epa.gov/cleandiesel/documents/420s06002.pdf
EPA 2006d	EPA Staff Communication: "Mobile Source Control Measures in PM NAAQS	
EPA 2006e	of September 2006	http://www.epa.gov/cleandiesel/ports/stratapp.htm#highway
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Pechan 2006	E.H. Pechan & Associates, Inc., "AirControlNET, Version 4.1 Control Measure Documentation Report," Draft Report, prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, Pechan Report No.	
San Joaquin Valley UAPCD, 2003	San Joaquin Valley Unified Air Pollution Control District (UAPCD). Final BACM Technological and Economic Feasibility Analysis, prepared by Sierra Research, March 21, 2003. www.soiltac.com/PDF/Final_BACM_Chapter 20 -	
STAPPA/ALAPCO 2006	The State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials, "Controlling Fine Particulate Matter Under the Clean Air Act: A Menu of Options, " March 2006	http://www.4cleanair.org/PM25Menu-Final.pdf
TCEQ 2006	Texas Commission on Environmental Quality, Texas Air Quality Control	http://www.tceq.state.tx.us/implementation/air/sip/sipstrategies.html#mobile

Nonroad PM Control Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Nonroad Diesel Engines except locomotive, marine, pleasure craft, and aircraft engine	Nonroad Retrofit DOC	20	11,600 - 63,300	Low end of range represents most cost-effective retrofits (first 50% of retrofit potential). High end of range represents least cost-effective retrofits (second 50% of retrofit potential). PM cost effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild). Cost effectiveness values were calculated by EPA based on the cost for DOC applied to a 250 hp bulldozer. However, this measure is intended to apply to all nonroad engines, model year 1988-2007, except for locomotive, marine, pleasure craft, and aircraft engines.	VOC	EPA, 2006a EPA, 2006b
Nonroad Diesel Engines except locomotive, marine, pleasure craft, and aircraft engine	Nonroad Retrofit DPF	90	9,700 - 52,700	Low end of range represents most cost-effective retrofits (first 50% of retrofit potential). High end of range represents least cost-effective retrofits (second 50% of retrofit potential). PM cost effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild). Cost effectiveness values were calculated by EPA based on the cost for DOC applied to a 250 hp bulldozer. However, this measure is intended to apply to all nonroad engines, model year 1988-2007, except for locomotive, marine, pleasure craft, and aircraft engines.	VOC	EPA, 2006a EPA, 2006b
Nonroad Diesel Engines except locomotive, marine, pleasure craft, and aircraft engine	Nonroad Engine Upgrade	20			NOx, VOC	EPA, 2006a
Nonroad Diesel Engines	Early Use of Ultra-Low Sulfur Diesel			Some direct PM reductions would result due to lower S content of fuel	SO2	EPA, 2006c
Nonroad Diesel Engines	Early Use of Ultra-Low Sulfur Diesel + Retrofit			Some retrofits that rely on ULSD (e.g., DPFs) that have been verified by EPA and/or CARB require a S content of no more than 15-50ppm.	SO2	EPA, 2006c
Nonroad Diesel Construction	Engine/Equipment Replacement (Scrappage)		2,000-25,000	Only emission reductions reported, no control efficiencies. Emission reductions and Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Cost effectiveness expressed as dollar per ton NOx reduced.	NOx	ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Engine/Equipment Replacement (Scrappage)		7,000-84,000	Only emission reductions reported, no control efficiencies. Emission reductions and Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Cost effectiveness expressed as dollar per ton NOx reduced.	NOx	ENVIRON, 2006 EPA, 2005
Nonroad Diesel Engines	Establish Opacity or other Emission Standards for "Gross-Emitting" Diesel Equipment or Vessels					EPA, 2005
Nonroad Engines	Low Emission Specifications - Limit emissions for construction projects, industrial facilities, ship yards, airports					EPA, 2005
Nonroad Engines	Expand Use of Clean Burning Fuels					EPA, 2005
Nonroad Gasoline	Equipment Replacement - Lawn Mower Buy Back Program			Program encourages trading of gasoline-powered mowers by providing funds to offset the purchase cost of electric mowers.		SCAQMD, 2006
Recreational Marine	Variable Registration Fees for Boat Engines			This control measure would require owners to register boat engines. The boat engine registration fee schedule would be designed so that lower fees would be assessed for the newest engines.	VOC	NJDEP, 2005
Nonroad Diesel Industrial	Operational Changes at Ports - Reduce Use of Mobile Diesel-powered Material-Handling Equipment			Reduce use of mobile diesel-powered material-handling equipment in favor of electric-powered stationary cranes. No emission reduction or cost information provided.		STAPPA/ALAPCO, 2006 CARB, 2005
Nonroad Diesel Industrial	ARB Cargo Handling Equipment Rule - Application of Best Available Control Technology	25-85	6,500-18,000	Range of CE values represents Level 1, 2 and 3, which are three benchmarks that control systems can be verified to. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	NOx	CARB, 2006
Locomotives	Idling Reduction - SmartStart and Diesel Driven Heating System	40-60	809	Idle reduction technologies can reduce idling up to 90 percent, depending on which technology is employed in which application. Control efficiencies provided correspond to a 90 percent reduction in idling, which is expected to reduce fuel consumption by 40 to 60 percent. PM and NOx cost per ton is an upper bound value, since savings due to reduced maintenance costs not accounted for.	NOx	NJDEP, 2005 Union Pacific, 2006 Vancouver, 2005, EPA 2004
Locomotives	Reduce Idling for Locomotives					EPA, 2005; EPA 2004
Locomotives	I&M for Locomotives - Conduct Opacity Testing and Conduct Repairs			This program is a voluntary agreement with the BNSF Railway Company and the Union Pacific Railroad Company to reduce PM emissions in California rail yards.		STAPPA/ALAPCO, 2006 CARB, 2005

Nonroad PM Control Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Switch Locomotive	Upgrade Engines in Switcher Locomotives - Diesel-electric hybrid locomotives	80	6,500-18,000	Hybrid switch locomotives have significantly reduced diesel PM and NOx emissions, idling time, and fuel use compared to conventional switchers. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	NOx	CARB, 2006
Switch Locomotive	Upgrade Engines in Switcher Locomotives - Install multiple off-road diesel engines	80	6,500-18,000	Remanufactured switchers are powered with two or three (700 hp) Tier 3 non-road diesel engines call gen-sets instead of conventional diesel locomotive engines. Gen-set locomotive manufacturers report that these locomotives can reduce fuel consumption by 20 to 35 percent. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	NOx	CARB, 2006
Locomotives	Locomotive Retrofit - DPF	>85		Has not been tested or used in rail yard applications in the U.S.		CARB, 2006
Locomotives	Locomotive Retrofit - DOC	20-50		Has not been tested or used in rail yard applications in the U.S.		CARB, 2006
Locomotives	Use of Alternative Fuels - Biodiesel	>50	6,500-18,000	Biodiesel generally results in a NOx increase, and is best used in combination with NOx control strategies. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.		CARB, 2006
Locomotives	Use of Alternative Fuels - Fisher-Tropsch Diesel		6,500-18,000	Made from converting synthetic gas to a liquid hydrocarbon diesel, this synthetic diesel fuel contains less than 10 ppm sulfur, which directly reduces diesel PM and SOx emissions. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.		CARB, 2006
Commercial Marine Vessels	Add-On Controls - DPF	>85				CARB, 2006
Commercial Marine Vessels	Add-On Controls - DOC	~30				CARB, 2006
Commercial Marine Vessels-Harbor Vessels	Cleaner Marine Fuels - Emulsified Diesel Fuel			ARB estimates that emulsified diesel fuel used in on-road engines can reduce NOx by 15 percent and PM by 50 percent. Additional testing is required to determine whether similar reductions are possible in marine engines.		CARB, 2006
Commercial Marine Vessels-Harbor Vessels	Cleaner Marine Fuels - Biodiesel	>50		Generally results in a NOx increase. Biodiesel is best used in combination with NOx control strategies.		CARB, 2006
Commercial Marine Vessels-Harbor Vessels	Cleaner Marine Fuels - Compressed or liquefied natural gas or diesel/CNG dual fuel			Can result in significant reductions in NOx and PM. The results vary with specific application and the ratio of diesel to CNG used. Additional testing is required to determine whether similar reductions are possible in marine engines.		CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Main Engines - Marine distillate fuels	75	6,500-18,000	Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	SO2	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Main Engines - Lower sulfur content	35	6,500-18,000	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	SO2	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Auxiliary Engines - Lower sulfur content	35	6,500-18,000	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	SO2	CARB, 2006
Commercial Marine Vessels Recreational Marine	Reduce Fuel Sulfur Content for Smaller Commercial and Recreational Vessels	10		Emission reductions based on assumption that current sulfur level of 3,000 parts per million (ppm) is reduced to 500 and to 15 ppm.	SO2	NJDEP, 2005
Commercial Marine Vessels-Ocean Going Vessels	Shore Based Electrical Power - Cold Ironing	90	6,500-18,000	ARB assumes 90% control and participation of 20% of fleet in 2010 and 80% of fleet in 2020. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	NOx	CARB, 2006
Commercial Marine Vessels-Harbor Vessels	Shore Based Electrical Power - Cold Ironing	12-27		No cost effectiveness values provided; likely to be cost-effective for ships that frequently visit ports equipped with shore power. Control efficiencies based on participation of 40% of tugboat fleet in 2010 and 80-100% of tugboat fleet in 2025.	NOx	CARB, 2006
Commercial Marine Vessels	Shore Based Electrical Power - Cold Ironing	83-97	69,000 (average) 16,000 (average weighted across all ships in study)	Cost effectiveness expressed as dollar per ton of VOC, NOx, CO, PM10 and SO2 reduction combined. Cost effectiveness would improve in the case of new terminals or new vessels, due to the lack of operational, safety, and engineering challenges associated with retrofitting shore power into existing port facilities.	NOx, SO2, VOC, CO	Environ, 2004 NJDEP, 2005

NOTES: Unless otherwise noted, control efficiencies represent control values per engine or equipment; overall cost effectiveness would need to account for the fraction of the fleet to which controls were applied.

Acronyms
EGR - Exhaust Gas Recirculation
SCR - Selective Catalytic Reduction
DOC - Diesel Oxidation Catalysts
DPF - Diesel Particulate Filters
CCV - Closed Crankcase Ventilation
APU - Auxiliary Power Units
GSE - Ground Support Equipment
CNG - Compressed Natural Gas
LPG - Liquefied Petroleum Gas
IMO - International Marine Organization
ULSD - Ultra-Low Sulfur Diesel

Nonroad SO2 Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Nonroad Diesel Engines	Early Use of Ultra-Low Sulfur Diesel			Proportionate SO2 reductions would result due to lower S content of fuel	PM	EPA, 2006c
Nonroad Diesel Engines	Early Use of Ultra-Low Sulfur Diesel + Retrofit			Some retrofits that rely on ULSD (e.g., DPFs) that have been verified by EPA and/or CARB require a S content of no more than 15-50ppm.	PM	EPA, 2006c
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Main Engines - Marine distillate fuels	75	6,500-18,000		PM	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Main Engines - Lower sulfur content	80	6,500-18,000	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels for Auxiliary Engines - Lower sulfur content	80	6,500-18,000	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Commercial Marine Vessels Recreational Marine	Reduce Fuel Sulfur Content for Smaller Commercial and Recreational vVessels	82-99.5		Emission reductions based on assumption that current sulfur level of 3,000 parts per million (ppm) is reduced to 500 and to 15 ppm.	PM	NJDEP, 2005

Acronyms
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DOC - Diesel Oxidation Catalysts
DPF - Diesel Particulate Filters
CCV - Closed Crankcase Ventilation
APU - Auxiliary Power Units
GSE - Ground Support Equipment
CNG - Compressed Natural Gas
LPG - Liquefied Petroleum Gas
IMO - International Marine Organization
ULSD - Ultra-Low Sulfur Diesel

Nonroad NOx Control Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Nonroad Diesel Construction	Engine/Equipment Replacement (Scrappage)		2,000-25,000	Only emission reductions reported, no control efficiencies. Emission reductions and Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.	PM	ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Engine/Equipment Replacement (Scrappage)		7,000-84,000	Only emission reductions reported, no control efficiencies. Emission reductions and Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.	PM	ENVIRON, 2006 EPA, 2005
Nonroad Diesel Construction	Nonroad NOx Retrofit - Lean NOx Catalyst	40	3,000-54,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Construction	Nonroad NOx Retrofit - EGR+DPF	50	7,000-108,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Construction	Nonroad NOx Retrofit - SCR	70-99	2,000-40,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Nonroad NOx Retrofit - Lean NOx Catalyst	40	9,000-91,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Nonroad NOx Retrofit - EGR+DPF	50	16,000-147,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Nonroad NOx Retrofit - SCR	70-99	7,000-67,000	Cost effectiveness values by equipment application, horsepower and technology type reported in Appendices to LADCO report. Earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Engines	Nonroad Engine Upgrade - Low end	30	1,600	Low end represents most cost-effective retrofits (first 50% of retrofit potential). Cost effectiveness based on low-end of range for DOC applied to 250 hp bulldozers. Cost effectiveness based on the same methodology as used in the PM cost effectiveness paper.	PM, VOC	EPA, 2006a EPA, 2006b
Nonroad Diesel Engines	Nonroad Engine Upgrade - High end	30	7,200	High end represents least cost-effective retrofits (second 50% of retrofit potential). Cost effectiveness based on average of range for DOC applied to 250 hp bulldozers. Cost effectiveness based on the same methodology as used in the PM cost effectiveness paper.	PM, VOC	EPA, 2006a EPA, 2006b
Nonroad Diesel	"Carl Moyer/TERP"-Type Voluntary Program - Nonroad Diesel Retrofit		1,800-7,300			OTC, 2006
Nonroad Gasoline Industrial	ARB Forklift and Other Industrial Equipment Rule - Tighter NOx and VOC Limits Plus Accelerated Replacement					CARB, 2006
Nonroad Diesel Construction	Emulsified Diesel Fuel	18	15,000-160,000	Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower and earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005
Nonroad Diesel Agriculture	Emulsified Diesel Fuel	18	15,000-50,000	Cost effectiveness values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower and earlier technology type engines are generally more cost-effective.		ENVIRON, 2006 EPA, 2005

Nonroad NOx Control Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Nonroad Diesel Construction	Nonroad Idling Reduction - Automatic Shut-off Devices			Control efficiencies will be variable. For example, if 20% reduction in idling is achievable, 225 tpy NOx and 18 tpy PM2.5 reduction would result in NJ. Reduction in fuel and engine maintenance costs, increased equipment life, and decreased noise complaints. Cost of technology would be recouped within the life of the equipment, probably sooner in many cases, providing a net cost savings for equipment owner.		NJDEP, 2005
Locomotives	Idling Reduction - SmartStart and Diesel Driven Heating System	40-60	$809	Idle reduction technologies can reduce idling up to 90 percent. Control efficiencies provided correspond to a 90 percent reduction in idling, which is expected to reduce fuel consumption by 40 to 60 percent. Cost per ton is an upper bound value, since savings due to reduced maintenance costs not accounted for.	PM	NJDEP, 2005 Union Pacific, 2006 Vancouver, 2005, EPA 2004
Switch Locomotive	Upgrade Engines in Switcher Locomotives - Diesel-electric hybrid locomotives	80	6,500-18,000	Hybrid switch locomotives have significantly reduced diesel PM and NOx emissions, idling time, and fuel use compared to conventional switchers. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Switch Locomotive	Upgrade Engines in Switcher Locomotives - Install multiple off-road diesel engines	80	6,500-18,000	Remanufactured switchers are powered with two or three (700 hp) Tier 3 non-road diesel engines call gen-sets instead of conventional diesel locomotive engines. Gen-set locomotive manufacturers report that these locomotives can reduce fuel consumption by 20 to 35 percent. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Commercial Marine Vessels	Add-On Controls - SCR	65-90		May reduce diesel PM emissions.	PM	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Cleaner Marine Fuels - Emulsified Diesel Fuel	30	6,500-18,000	Slight increase in fuel consumption and PM emissions. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.		CARB, 2006
Commercial Marine Vessels-Harbor Vessels	Cleaner Marine Fuels - Emulsified Diesel Fuel			ARB estimates that emulsified diesel fuel used in on-road engines can reduce NOx by 15 percent and PM by 50 percent. Additional testing is required to determine whether similar reductions are possible in marine engines.	PM	CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Vessel Speed Reduction Program - Extending Speed Reduction Zones Offshore		6,500-18,000	Slower speeds reduce main engine fuel consumption and result in significant NOx reductions. There is the potential for increases in diesel PM emissions for some vessels operating at slow speeds. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.		CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Shore Based Electrical Power - Cold Ironing	90	6,500-18,000	ARB assumes 90% control and participation of 20% of fleet in 2010 and 80% of fleet in 2020. Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Commercial Marine Vessels - Ocean-Going Vessels	Shore Based Electrical Power - Cold Ironing	99	69,000 (average) 16,000 (average weighted across all ships in study)	Cost effectiveness expressed as dollar per ton of VOC, NOx, CO, PM10 and SO2 reduction combined. Cost effectiveness would improve in the case of new terminals or new vessels, due to the lack of operational, safety, and engineering challenges associated with retrofitting shore power into existing port facilities.	PM	NJDEP, 2005 Environ, 2004
Commercial Marine Vessels-Harbor Vessels	Shore Based Electrical Power - Cold Ironing	12-27		No cost effectiveness values provided; likely to be cost-effective for ships that frequently visit ports equipped with shore power. Control efficiency represents overall control effectiveness based on participation of 40% of tugboat fleet in 2010 and 80-100% of tugboat fleet in 2025.		CARB, 2006
Commercial Marine Vessels-Ocean Going Vessels	Build or Retrofit New Ships that Far Exceed IMO Standards	90	6,500-18,000	Cost effectiveness expressed as dollar per ton of NOx + diesel PM reduced.	PM	CARB, 2006
Aircraft Ground Support Equipment	Alternative Fuels for Airport GSE - Replace Diesel GSE with CNG/LPG	65	1,000 - 3,000	Cost-effectiveness is expressed in dollar per ton VOC/CO/NOx combined	VOC	MRPO, 2005 NESCAUM, 2003

Nonroad NOx Control Measures

Source Category	Emissions Reduction Measure	Control Efficiency (%)	Cost Effectiveness, $/ton	Notes/Caveats	Other Pollutants Controlled	References for More Information
Aircraft Ground Support Equipment	Alternative Fuels for Airport GSE - Convert Gas GSE to CNG/LPG	25	Overall cost savings from reduced fuel use		VOC	MRPO, 2005 NESCAUM, 2003
Aircraft Ground Support Equipment	Alternative Fuels for Airport GSE - Replace Diesel GSE with Electric	100	Cost savings - $5,800	Cost savings or net costs dependent on type of GSE. Savings for belt loader, costs incurred for baggage tractor and aircraft tug.		MRPO, 2005 NESCAUM, 2003
Aircraft Ground Support Equipment	Alternative Fuels for Airport GSE - Replace Gas GSE with Electric	100	Cost savings - $1,900	Cost savings or net costs dependent on type of GSE. Savings for belt loader and aircraft tug, costs incurred for baggage tractor.		MRPO, 2005 NESCAUM, 2003
Aircraft Ground Support Equipment	Gate Electrification to Reduce GSE/APU Use - Retrofit Airport Gates with Power and Preconditioned Air			No emission reduction or Cost effectiveness values provided. Gate electrification requires an up-front capital investment but, once installed, the system produces fuel and labor savings that typically result in a relatively short payback time of less than two years.		NESCAUM, 2003
Aircraft Ground Support Equipment	Nonroad Idling Reduction			Control efficiencies will be variable. For example, applying the current 3-minute idling law to the approx. 2000 non-road GSEs in NJ will result in fuel savings and reduced engine wear and is a low cost strategy.		NJDEP, 2005

NOTES: Unless otherwise noted, control efficiencies represent control values per engine or equipment; overall cost effectiveness would need to account for the fraction of the fleet to which controls were applied.

Acronyms

EGR - Exhaust Gas Recirculation
SCR - Selective Catalytic Reduction
DOC - Diesel Oxidation Catalysts
DPF - Diesel Particulate Filters
CCV - Closed Crankcase Ventilation
APU - Auxiliary Power Units
GSE - Ground Support Equipment
CNG - Compressed Natural Gas
LPG - Liquefied Petroleum Gas
IMO - International Marine Organization
ULSD - Ultra-Low Sulfur Diesel

Nonroad Control Measures References

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ENVIRON, 2006	ENVIRON International Corporation, "Evaluation of Candidate Mobile Source Control Measures", Final Report, prepared for Lake Michigan Air Directors Consortium, 2250 E. Devon Ave., #250, Des Plaines, IL 60018, February 28, 2006.	http://www.ladco.org/reports/rpo/Regional%20Air%20Quality/LADCO%20Control%20Report_Final.pdf
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EPA, 2006b	U.S. Environmental Protection Agency, Office of Transportation and Air Quality, "Diesel Retrofit Technology, An Analysis of the Cost-Effectiveness of Reducing Particulate Matter Emissions from Heavy-Duty Diesel Engines Through Retrofits", EPA420-S-06-002, March 2006.	http://www.epa.gov/cleandiesel/documents/420s06002.pdf
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NESCAUM, 2003	Northeast States for Coordinated Air Use Management (NESCAUM). Controlling Airport-Related Air Pollution. June 2003.	http://www.nescaum.org/documents/aviation_final_report.pdf/view?searchterm=Airport
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Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%) PM 2.5	PM	SO2	NH3	NOx	VOC	CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
ENVIRON, 2006	NOx	Nonroad diesel	Nonroad Mobile Sources	California Diesel Fuel	Aromatic hydrocarbon content of 10%		2270xxxxxx					6		ENVIRON, 2006	8,000	2007	ENVIRON, 2006	California Fuels measure will also reduce sulfur levels and decrease PM, but Federal Diesel Regulations will provide equivalent PM reductions
SCAQMD, 2006	NOx	Nonroad Diesel	Nonroad Mobile Sources	Nonroad Diesel Retrofit	SCR		2270xxxxxx					98		SCAQMD, 2006				Reduction on new installations. NOx reduction technologies may result in larger PM emissions and reduced fuel efficiency.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 0	2270005xxx					18		EPA, 2005	15,000-22,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 1	2270005xxx					18		EPA, 2005	21,000-23,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 2	2270005xxx					18		EPA, 2005	29,000-31,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 3	2270005xxx					18		EPA, 2005	48,000-50,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 0 with Tier 2 engines	Tier 0	2270005xxx							EPA, 2005	7,000-26,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 1 with Tier 3 engines	Tier 1	2270005xxx							EPA, 2005	11,000-36,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 2 with Tier 3 engines	Tier 2	2270005xxx							EPA, 2005	22,000-84,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 0	2270005xxx					40		EPA, 2005	9,000-28,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 1	2270005xxx					40		EPA, 2005	12,000-38,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 2	2270005xxx					40		EPA, 2005	18,000-57,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 3	2270005xxx					40		EPA, 2005	30,000-91,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 0	2270005xxx					50		EPA, 2005	16,000-45,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 1	2270005xxx					50		EPA, 2005	22,000-61,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 2	2270005xxx					50		EPA, 2005	33,000-92,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 3	2270005xxx					50		EPA, 2005	54,000-147,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 0	2270005xxx					70-99		EPA, 2005	7,000-20,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 1	2270005xxx					70-99		EPA, 2005	9,000-28,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 2	2270005xxx					70-99		EPA, 2005	14,000-42,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Agriculture	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 3	2270005xxx					70-99		EPA, 2005	22,000-67,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
OTC, 2006	NOx	Nonroad Diesel Agriculture Nonroad Diesel Construction Locomotives Commercial Marine Vessels	Nonroad Mobile Sources	"Carl Moyer/TERP"-Type Voluntary Program	Nonroad Diesel Retrofit		2270005xxx 2270002xxx 2285002xxx 2280002xxx								$1,800-$7,300		OTC, 2006	
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 0	2270002xxx					18		EPA, 2005	15,000-50,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 1	2270002xxx					18		EPA, 2005	21,000-68,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 2	2270002xxx					18		EPA, 2005	31,000-100,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Emulsified Diesel Fuel	Emulsified Diesel Fuel	Tier 3	2270002xxx					18		EPA, 2005	50,000-160,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report. Smaller horsepower engines are generally more cost-effective.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 0 with Tier 2 engines	Tier 0	2270002xxx							EPA, 2005	2,000-8,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 1 with Tier 3 engines	Tier 1	2270002xxx							EPA, 2005	4,000-11,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Engine/Equipment Replacement (Scrappage)	Replace Tier 2 with Tier 3 engines	Tier 2	2270002xxx							EPA, 2005	9,000-25,000	2007	ENVIRON, 2006	Only emission reductions reported, no control efficiencies. Emission reductions and C-E values by equipment application, horsepower and technology type are reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 0	2270002xxx					40		EPA, 2005	3,000-16,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 1	2270002xxx					40		EPA, 2005	4,000-22,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 2	2270002xxx					40		EPA, 2005	6,000-33,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	Lean NOx Catalyst	Tier 3	2270002xxx					40		EPA, 2005	12,000-54,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 0	2270002xxx					50		EPA, 2005	7,000-32,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 1	2270002xxx					50		EPA, 2005	9,000-45,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 2	2270002xxx					50		EPA, 2005	13,000-66,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	EGR+DPF	Tier 3	2270002xxx					50		EPA, 2005	26,000-108,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 0	2270002xxx					70-99		EPA, 2005	2,000-12,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 1	2270002xxx					70-99		EPA, 2005	3,000-17,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 2	2270002xxx					70-99		EPA, 2005	4,000-25,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
ENVIRON, 2006	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad NOx Retrofit	SCR	Tier 3	2270002xxx					70-99		EPA, 2005	9,000-40,000	2007	ENVIRON, 2006	C-E values by equipment application, horsepower and technology type reported in Appendices to LADCO report.
NJDEP, 2005	NOx	Nonroad Diesel Construction	Nonroad Mobile Sources	Nonroad Idling Requirements	Automatic Shut-off Devices		2270002xxx											Control efficiencies will be variable. For example, if 20% reduction in idling is achievable, 225 tpy NOx and 18 tpy PM2.5 reduction would result in NJ. Reduction in fuel and engine maintenance costs, increased equipment life, and decreased noise complaints. Cost of technology would be recouped within the life of the equipment, probably sooner in many cases, providing a net cost savings for equipment owner.
OTC, 2006	PM	Nonroad Diesel Construction	Nonroad Mobile Sources	Clean Air Construction Initiative	Nonroad Diesel Retrofit		2270002xxx								$ per ton varies		OTC, 2006	
EPA, 2006a	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - Low end	DPF	1988-2007	2270xxxxxx		90				90		18,100	2007	EPA, 2006b	Low end represents most cost-effective retrofits (first 50% of retrofit potential). Cost-effectiveness based on low-end of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%) PM 2.5	PM	SO2	NH3	NOx	VOC	CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
EPA, 2006a	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - High end	DPF	1988-2007	2270xxxxxx		90				90		33,900	2007	EPA, 2006b	High end represents least cost-effective retrofits (second 50% of retrofit potential). Cost-effectiveness based on average of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)
EPA, 2006a	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - Low end	DOC	1988-2007	2270xxxxxx		20				50		18,100	2007	EPA, 2006b	Low end represents most cost-effective retrofits (first 50% of retrofit potential). Cost-effectiveness based on low-end of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)
EPA, 2006a	PM/NOx	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - Low end	Rebuild	1988-2007	2270xxxxxx		20			30	60		18,100	2007	EPA, 2006b	Low end represents most cost-effective retrofits (first 50% of retrofit potential). Cost-effectiveness based on low-end of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
EPA, 2006a	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - High end	DOC	1988-2007	2270xxxxxx		20				50		33,900	2007	EPA, 2006b	High end represents least cost-effective retrofits (second 50% of retrofit potential). Cost-effectiveness based on average of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)
EPA, 2006a	PM/NOx	Nonroad Diesel Engines	Nonroad Mobile Sources	Nonroad Retrofit - High end	Rebuild	1988-2007	2270xxxxxx		20			30	60		33,900	2007	EPA, 2006b	High end represents least cost-effective retrofits (second 50% of retrofit potential). Cost-effectiveness based on average of range for DOC applied to 250 hp bulldozers. PM cost-effectiveness values apply for all retrofit measures combined (DOC, DPF, and rebuild)
EPA, 2006c	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Early Use of Ultra-Low Sulfur Diesel	Early Use of Ultra-Low Sulfur Diesel		2270xxxxxx											Some direct PM reductions would result due to lower S content of fuel
EPA, 2006c	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Early Use of Ultra-Low Sulfur Diesel + Retrofit	Early Use of Ultra-Low Sulfur Diesel + Retrofit		2270xxxxxx											Some retrofits that rely on ULSD (e.g., DPFs) that have been verified by EPA and/or CARB require a S content of no more than 15-50ppm.
EPA, 2005	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Clean Burning Fuels	Prohibit Sale and Use of Diesel that Exceeds High S Content		2270xxxxxx											

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
EPA, 2005	PM	Nonroad Diesel Engines	Nonroad Mobile Sources	Standards for "Gross-Emitting" Equipment	Establish Opacity or other Emission Standards for Diesel Equipment or Vessels		2270xxxxxx 2280002xxx											
EPA, 2006c	SO2	Nonroad Diesel Engines	Nonroad Mobile Sources	Early Use of Ultra-Low Sulfur Diesel	Early Use of Ultra-Low Sulfur Diesel		2270xxxxxx											Proportionate SO2 reductions would result due to lower S content of fuel
CARB, 2006	PM	Nonroad diesel industrial	Nonroad Mobile Sources	ARB Cargo Handling Equipment Rule	Application of Best Available Control Technology	Level 3	2270003xxx 2270002xxx		85					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Level 1, 2 and 3 represent three benchmarks that control systems can be verified to.
CARB, 2006	PM	Nonroad diesel industrial	Nonroad Mobile Sources	ARB Cargo Handling Equipment Rule	Application of Best Available Control Technology	Level 2	2270003xxx 2270002xxx		50					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Level 1, 2 and 3 represent three benchmarks that control systems can be verified to.
CARB, 2006	PM	Nonroad diesel industrial	Nonroad Mobile Sources	ARB Cargo Handling Equipment Rule	Application of Best Available Control Technology	Level 1	2270003xxx 2270002xxx		25					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Level 1, 2 and 3 represent three benchmarks that control systems can be verified to.
STAPPA/ALAPCO, 2006	PM	Nonroad diesel industrial	Nonroad Mobile Sources	Operational Changes at Ports	Reduce Use of Mobile Diesel-powered Material-Handling Equipment In Favor of Electric-powered		2270003xxx 2270002xxx							CARB, 2005				This program is a voluntary agreement with the BNSF Railway Company and the Union Pacific Railroad Company to reduce PM emissions in California rail yards.
EPA, 2005	PM	Nonroad Engines	Nonroad Mobile Sources	Early Retirement/Scrappage	Programs to Reduce Emissions and Accelerate Retirement of Boats and Lawn and Garden Equipment		2260xxxxxx 2265xxxxxx 2270xxxxxx											

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
EPA, 2005	PM	Nonroad Engines	Nonroad Mobile Sources	Low Emission Specifications	Limit emissions for construction projects, industrial facilities, ship yards, airports		2260xxxxxx 2265xxxxxx 2270xxxxxx											
EPA, 2005	PM	Nonroad Engines	Nonroad Mobile Sources	Clean Burning Fuels	Expand Use of Clean Burning Fuels		2260xxxxxx 2265xxxxxx 2270xxxxxx											
SCAQMD, 2006	PM	Nonroad Gasoline	Nonroad Mobile Sources	Equipment Replacement	Lawn Mower Buy Back Program		2260004xxx 2265004xxx											Program encourages trading of gasoline-powered mowers by providing funds to offset the purchase cost of electric mowers.
CARB, 2006	NOx	Nonroad gasoline industrial	Nonroad Mobile Sources	ARB Forklift and Other Industrial Equipment Rule	Tighter NOx and VOC Limits Plus Accelerated Replacement		2260003xxx 2265003xxx											
NJDEP, 2005	PM/VOC	Recreational Marine	Nonroad Mobile Sources	Variable Registration Fees for Boat Engines	Boat Engine Registration		228202xxxx											This control measure would require owners to register boat engines. The boat engine registration fee schedule would be designed so that lower fees would be assessed for the newest engines.
MRPO, 2005	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Alternative Fuels for Airport GSE	Replace Diesel GSE with CNG/LPG		2270008xxx					65	30	NESCAUM, 2003	1,000 - 3,000		NESCAUM, 2003	Cost-effectiveness is expressed in dollar per ton VOC/CO/NOx combined
MRPO, 2005	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Alternative Fuels for Airport GSE	Convert Gas GSE to CNG/LPG		2260008xxx 2265008xxx					25	50-70	NESCAUM, 2003	Overall cost savings from reduced fuel use		NESCAUM, 2003	
MRPO, 2005	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Alternative Fuels for Airport GSE	Replace Diesel GSE with Electric		2270008xxx					100		NESCAUM, 2003	Cost savings - $5,800		NESCAUM, 2003	Cost savings or net costs dependent on type of GSE. Savings for belt loader, costs incurred for baggage tractor and aircraft tug.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
MRPO, 2005	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Alternative Fuels for Airport GSE	Replace Gas GSE with Electric		2260008xxx 2265008xxx					100		NESCAUM, 2003	Cost savings - $1,900		NESCAUM, 2003	Cost savings or net costs dependent on type of GSE. Savings for belt loader and aircraft tug, costs incurred for baggage tractor.
NESCAUM, 2003	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Gate Electrification to Reduce GSE/APU Use	Retrofit airport gates with power and preconditioned air		2260008xxx 2265008xxx 2270008xxx 2275070000											No emission reduction or C-E values provided. Gate electrification requires an up-front capital investment but, once installed, the system produces fuel and labor savings that typically result in a relatively short payback time of less than two years.
NJDEP, 2005	NOx	Aircraft Ground Support Equipment	Nonroad Mobile Sources	Nonroad Idling Requirements	Restrict Idling to 3 minutes		2270008xxx											Control efficiencies will be variable. For example, applying the current 3-minute idling law to the approx. 2000 non-road GSEs in NJ will result in fuel savings and reduced engine wear and is a low cost strategy.
CARB, 2006	PM/NOx	Switch Locomotive	Nonroad Mobile Sources	Upgrade Engines in Switcher Locomotives	Diesel-electric hybrid locomotives		2285002010		80			80		CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Hybrid switch locomotives have significantly reduced diesel PM and NOx emissions, idling time, and fuel use compared to conventional switchers.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
CARB, 2006	PM/NOx	Switch Locomotive	Nonroad Mobile Sources	Upgrade Engines in Switcher Locomotives	Locomotives comprised of multiple off-road diesel engines		2285002010		80			80		CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Remanufactured switchers are powered with two or three (700 hp) Tier 3 non-road diesel engines call gen-sets instead of conventional diesel locomotive engines. Gen-set locomotive manufacturers report that these locomotives can reduce fuel consumption by 20 to 35 percent.
NJDEP, 2005	NOx/PM	Locomotives	Nonroad Mobile Sources	Idling Reduction	SmartStart and Diesel Driven Heating System		2285002xxx		40-60			40-60		Union Pacific, 2006	$809	2005	Vancouver, 2005	Idle reduction technologies can reduce idling up to 90 percent, depending on which technology is employed in which application. Control efficiencies provided correspond to a 90 percent reduction in idling, which is expected to reduce fuel consumption by 40 to 60 percent. PM and NOx cost per ton is an upper bound value, since savings due to reduced maintenance costs not accounted for.
CARB, 2006	PM	Locomotives	Nonroad Mobile Sources	Locomotive Retrofit	DOC		2285002xxx		20-50					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Has not been tested or used in rail yard applications in the U.S.
CARB, 2006	PM	Locomotives	Nonroad Mobile Sources	Locomotive Retrofit	DPF		2285002xxx		>85					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Has not been tested or used in rail yard applications in the U.S.
CARB, 2006	PM	Locomotives	Nonroad Mobile Sources	Use of Alternative Fuels	Biodiesel		2285002xxx		>50					CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Biodiesel generally results in a NOx increase, and is best used in combination with NOx control strategies.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
EPA, 2005	PM	Locomotives	Nonroad Mobile Sources	Diesel Idling Programs	Reduce Idling for Locomotives		2285002xxx											
STAPPA/ALAPCO, 2006	PM	Locomotives	Nonroad Mobile Sources	I&M for Locomotives	Conduct Opacity Testing and Conduct Repairs		2285002xxx							CARB, 2005				This program is a voluntary agreement with the BNSF Railway Company and the Union Pacific Railroad Company to reduce PM emissions in California rail yards.
CARB, 2006	PM	Locomotives	Nonroad Mobile Sources	Use of Alternative Fuels	Fisher-Tropsch Diesel		2285002xxx								$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Made from converting synthetic gas to a liquid hydrocarbon diesel, this synthetic diesel fuel contains less than 10 ppm sulfur, which directly reduces diesel PM and SOx emissions.
NJDEP, 2005	NOx/PM	Commercial Marine Vessels	Nonroad Mobile Sources	Provide Electric Power to Ships at the Ports	Cold Ironing		2280002xxx		83-97			99		Environ, 2004	$69,000/ton = average $16,000/ton = weighted average		Environ, 2004	Cost-effectiveness would improve in the case of new terminals or new vessels, due to the lack of operational, safety, and engineering challenges associated with retrofitting shorepower into existing port facilities.
CARB, 2006	PM	Commercial Marine Vessels	Nonroad Mobile Sources	Add-On Controls	DPF		2280002xxx		>85					CARB, 2006				There are two kinds of filters available - passive and active.
CARB, 2006	PM	Commercial Marine Vessels	Nonroad Mobile Sources	Add-On Controls	DOC		2280002xxx		~30					CARB, 2006				
NJDEP, 2005	SO2/PM	Commercial Marine Vessels	Nonroad Mobile Sources	Reduce Fuel Sulfur Content in Main Engines of Ocean-going vessels	Switch to Low Sulfur Fuel		2280002xxx		5	40				NJDEP, 2005				This measure must be implemented through petitioning EPA to generate a SECA application associated with MARPOL.
CARB, 2006	NOx	Commercial Marine Vessels	Nonroad Mobile Sources	Add-On Controls	SCR		2280002xxx					65-90		CARB, 2006				May reduce diesel PM emissions.

Nonroad Detailed Control Measure List

Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
NJDEP, 2005	SO2/PM	Commercial Marine Vessels	Nonroad Mobile Sources	Limit Sulfur Content of Auxiliary Engine Fuel	Switch to Low Sulfur Fuel		2280002xxx											California has predicted that their auxiliary engine rule will yield the following reductions: 2.7 tons per day (TPD) of PM in 2007 and 3.7 TPD of PM in 2010. California has predicted that their auxiliary engine fuel sulfur limit will cost the container and bulk shipping industry to reduce sulfur content of the fuel from 1% to 0.5% approximately $34 million in 2007. To further reduce the sulfur content of the fuel from 0.5% to 0.1% would cost approximately $38 million in 2010.
NJDEP, 2005	SO2/PM	Commercial Marine Vessels Recreational Marine	Nonroad Mobile Sources	Reduce Fuel Sulfur Content for Smaller Commercial and Recreational Vessels	Switch to Low Sulfur Fuel		2280002xxx 228202xxxx		10	82-99.5				NJDEP, 2005				Emission reductions based on assumption that current sulfur level of 3,000 parts per million (ppm) is reduced to 500 and to 15 ppm.
CARB, 2006	NOx/PM	Commercial Marine Vessels-Harbor Vessels	Nonroad Mobile Sources	Shore Based Electrical Power	Cold Ironing		2280002020		12-27			12-27		CARB, 2006				No C-E values provided; likely to be cost-effective for ships that frequently visit ports equipped with shore power. Control efficiencies based on participation of 40% of tugboat fleet in 2010 and 80-100% of tugboat fleet in 2025.
CARB, 2006	PM	Commercial Marine Vessels-Harbor Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels	Biodiesel		2280002020		>50					CARB, 2006				Generally results in a NOx increase. Biodiesel is best used in combination with NOx control strategies.

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Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
CARB, 2006	NOx	Commercial Marine Vessels-Harbor Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels	Emulsified Diesel Fuel		2280002020							CARB, 2006				ARB estimates that emulsified diesel fuel used in on-road engines can reduce NOx by 15 percent and PM by 50 percent. Additional testing is required to determine whether similar reductions are possible in marine engines.
CARB, 2006	PM	Commercial Marine Vessels-Harbor Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels	Compressed or liquefied natural gas or diesel/CNG dual fuel		2280002020											Can result in significant reductions in NOx and PM. The results vary with specific application and the ratio of diesel to CNG used. Additional testing is required to determine whether similar reductions are possible in marine engines.
CARB, 2006	NOx/PM	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Shore Based Electrical Power	Cold Ironing		2280002010		90			90			$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	ARB assumes 90% control and participation of 20% of fleet in 2010 and 80% of fleet in 2020
CARB, 2006	SO2/PM	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels for Main Engines	Marine distillate fuels		2280002010		75	75		6		CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	
CARB, 2006	NOx/PM	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Build New Ships that Far Exceed IMO Standards	New or Retrofitted Engines		2280002010		60			90		CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	
CARB, 2006	SO2	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels for Main Engines	Lower sulfur content		2280002010		35	80				CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm
CARB, 2007	SO2	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels for Auxiliary Engines	Lower sulfur content		2280002010		35	80				CARB, 2006	$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Control efficiencies assume use of lower sulfur content fuel oil of 5000 ppm

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Primary Reference	Major Pollutant	Source Category	Source Sector	Control Measure	Technology	Model Year	Applicable SCC Codes	Control Efficiency (%)						CE Reference	Cost Effectiveness	Cost Year	Cost Reference	Comments
								PM 2.5	PM	SO2	NH3	NOx	VOC					
CARB, 2006	NOx	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Cleaner Marine Fuels	Emulsified Diesel Fuel		2280002010					30			$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Slight increase in fuel consumption and PM emissions.
CARB, 2006	NOx	Commercial Marine Vessels-Ocean Going Vessels	Nonroad Mobile Sources	Vessel Speed Reduction Program	Extending speed reduction zones offshore		2280002010								$6,500-$18,000 per ton of NOx + diesel PM reduced	2005	CARB, 2006	Slower speeds reduce main engine fuel consumption and result in significant NOx reductions. There is the potential for increases in diesel PM emissions for some vessels operating at slow speeds.

Acronyms

EGR - Exhaust Gas Recirculation
SCR - Selective Catalytic Reduction
DOC - Diesel Oxidation Catalysts
DPF - Diesel Particulate Filters
CCV - Closed Crankcase Ventilation
APU - Auxiliary Power Units
GSE - Ground Support Equipment
CNG - Compressed Natural Gas
LPG - Liquefied Petroleum Gas
IMO - International Marine Organization
ULSD - Ultra-Low Sulfur Diesel

Onroad VOC Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
School Bus	Diesel Retrofit - Diesel Oxidation Catalysts	50	12000 - 49100	Applies to 1990-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
School Bus	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	12400 - 50500	Applies to 1995-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 6 & 7 HDDVs	Diesel Retrofit - Diesel Oxidation Catalysts	50	27600 - 67900	Applies to 1990-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 6 & 7 HDDVs	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	28400 - 69900	Applies to 1995-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 8B HDDVs	Diesel Retrofit - Diesel Oxidation Catalysts	50	11100 - 40600	Applies to 1990-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
Class 8B HDDVs	Diesel Retrofit - Catalyzed Diesel Particulate Filters	90	12100 - 44100	Applies to 1995-2006 model years	PM, CO	EPA 2006b, EPA 2006d, EPA 2006
HDDVs	Diesel Retrofit - Active Diesel Particulate Filter	60 - 93			PM, CO	STAPPA/ALAPCO 2006, EPA 2006
HDDVs	Diesel Retrofit - Flow Through Filter	50 - 89		Applies to 1991 - 2002 model years; needs 15 ppm sulfur diesel or CARB diesel	PM, CO	STAPPA/ALAPCO 2006; CARB 2006a, EPA 2006
HDDVs	Diesel Retrofit - NOX Adsorber	10 - 90			PM, NOX, CO	STAPPA/ALAPCO 2006, EPA 2006
HDDVs	Alternative Fuel - Biodiesel	0 - 50		Increases NOX	PM, CO	EPA 2006e; STAPPA/ALAPCO 2006
HDDVs	Alternative Fuel - Oxygenated Diesel	0 - 50		Oxygenated with ethanol; Nox emissions likely to increase	PM, CO, CO2	STAPPA/ALAPCO 2006
HDDVs	Alternative Fuel - Fuel-borne Catalyst	0 - 50			PM, NOX, CO	STAPPA/ALAPCO 2006
Class 5 and above HDDVs and Diesel Buses	Replacement	72 - 89		Applies to 1990-2006 model years	PM, NOX	EPA 2006d
Class 8 HDDVs	Intermodal - shift of transportation of goods from truck to rail transport	1.0	0	Would result in a 0.3-0.4% increase in all pollutants from locomotive and rail SCCs; represents a 1% shift from truck-only transport to	PM, NOX, SO2, NH3	EPA 2006d
Class 8 HDDVs	Eliminate Long Duration Idling with Truck Stop Electrification	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, NOX, SO2, CO	EPA 2006d, EPA 2004
Class 8 HDDVs	Eliminate Long Duration Idling with Mobile Idle Reduction Technologies	3.4	0	Upfront capital costs fully recovered by fuel savings	PM, NOX, SO2, CO	EPA 2006d, EPA 2004

Onroad VOC Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
Light-Duty Gasoline Vehicles and Trucks	Best Workplaces for Commuters- all measures combined	0.4-1.0		Reductions based on the following measures: Regional Rideshare, Vanpool Programs, Park-and-ride lots, Regional TDM, Employer trip reduction programs; control efficiency depends on penetration--0.4% reduction	PM, NOX, SO2, NH3, CO	EPA 2006d, EPA 2005b
LDGVs, LDGTs, HDGVs, and MCs	Federal Reformulated Gasoline	27			NOX, CO	Pechan 2006, EPA 1999
LDGVs and LDGTs	High Enhanced I/M Program	1.8 - 19.8		Reduction is based on emissions from entire fleet	NOX, CO	Pechan 2006
LDGVs and LDGTs	Repair assistance for low-income owners of older poorly maintained vehicles				NOX	NJDEP 2005b
LDGVs and LDGTs	Convert State and Large Corporate Fleets to Hybrid and/or alternate fuel				NOX, PM, SO2	NJDEP 2005b
LDGVs and LDGTs	MPG/Emissions Requirements for Large Fleets				NOX, PM, SO2	NJDEP 2005b
LDGVs and LDGTs	Fee based on VMT				NOX, PM, SO2,	NJDEP 2005b
LDGVs and LDGTs	Alternative Fuels Tax Credit					NJDEP 2005b
LDGVs and LDGTs	Electric Shuttles in Structured Communities				NOX, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Electric Vehicle Charging Stations				NOX, PM, SO2	NJDEP 2005b
LDGVs, LDGTs, HDGVs, and MCs	Increase fuel tax				NOX, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Expansion of Bike/hiking trails				NOX, PM, SO2, NH3	NJDEP 2005b
LDGVs and LDGTs	Ban drive-through windows at fast food and banks				NOX, PM, SO2	NJDEP 2005b
HDDVs	Driver incentive/training program to reduce idling				NOX, PM, SO2	NJDEP 2005a
HDDVs	Hybrid Power Train Technology			Provides fuel savings of 10% - 15%. Being tested by UPS and FedEx.	NOX, PM, SO2	NJDEP 2005a

Onroad VOC Measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
LDGVs and LDGTs	Incentives for hybrids and other ULEV, SULEV, ZEV vehicles				NOX, PM, SO2	CARB 2006b
All Highway Vehicles	Smoking Vehicle Hotline				PM, NOX	CARB 2006b

Acronyms:

LDGV=Light-duty Gasoline Vehicle
LDGT=Light-duty Gasoline Truck
HDGV=Heavy-duty Gasoline Vehicle
MC=Motorcycle
LDDV=Light-duty Diesel Vehicle
LDDT=Light-duty Diesel Truck
HDDV=Heavy-duty Diesel Vehicle

Onroad NH3 measures

Source Category	Emission Reduction Measure	Control Efficiency	Cost Effectiveness	Notes/caveats	Other pollutants controlled	References for more information
Class 8 HDDVs	Intermodal - shift of transportation of goods from truck to rail transport	1.0	0	Would result in a 0.3-0.4% increase in all pollutants from locomotive and rail SCCs; represents a 1% shift from truck-only transport to rail	PM, NOX, SO2, VOC	EPA 2006d
LDGVs and LDGTs	Best Workplaces for Commuters- all measures combined	0.4-1.0		Reductions based on the following measures: Regional Rideshare, Vanpool Programs, Park-and-ride lots, Regional TDM, Employer trip reduction programs; control efficiency depends on penetration--0.4% reduction at 10% penetration and 1.0% reduction at 25% penetration	PM, NOX, VOC, SO2, CO	EPA 2006d, EPA 2005B
LDGVs and LDGTs	Fee based on VMT				VOC, NOX, PM,	NJDEP 2005b
LDGVs and LDGTs	Electric Shuttles in Structured Communities				VOC, NOX, PM, SO2	NJDEP 2005b
LDGVs, LDGTs, HDGVs, and MCs	Increase fuel tax				VOC, NOX, PM, SO2	NJDEP 2005b
LDGVs and LDGTs	Expansion of Bike/hiking trails				VOC, NOX, PM,	NJDEP 2005b

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Stationary and Area NH3 Measures

Source category	Emissions reduction measure	Control efficiency (%)	Cost effectiveness ($/ton reduced)	Cost Year	Notes/caveats	Other pollutants controlled	References for more information
Animal Feeding Operations	Adopt emerging animal feeding operation control technologies	70 (swine), 55 (dairy)	approx $10,000	1999$	Development measure from PM NAAQS RIA		EPA 2006
Animal Feeding Operations	Chemical additives to animal waste	50 (cattle), 50 (hogs), 75 (poultry)	$228 (cattle), 50% (hogs), $1,014 (poultry)	1999$			Pechan 2006

Onroad VOC and NH3 Measure References

Key For Tables	Complete Reference	URL
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Onroad VOC and NH3 Measure References

Key For Tables	Complete Reference	URL
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